TECHNICAL MEMORANDUM NO. 3-240

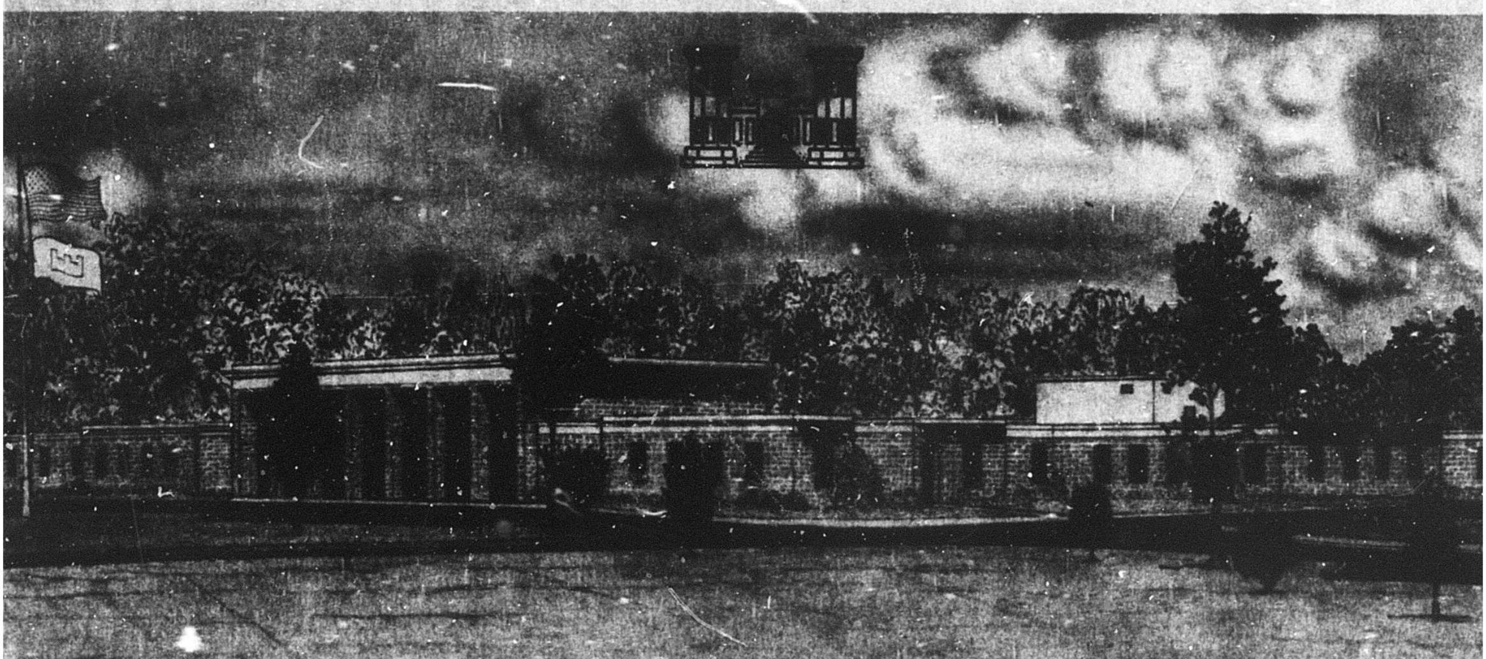
TRAFFICABILITY OF SOILS

Nineteenth Supplement

EFFECTS OF SURFACE CONDITIONS ON DRAWBAR PULL OF A WHEELED VEHICLE

by

E. S. Rush, J. H. Robinson



April 1971

Sponsored by U. S. Army Materiel Command

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

REPORTS OF THE SERIES ENTITLED "TRAFFICABILITY OF SOILS"
TECHNICAL MEMORANDUM NO. 3-240

Supplement No.	Title	Date
	Pilot Tests--Self-Propelled Vehicles	Nov. 1947
1	Laboratory Tests to Determine Effects of Moisture Content and Density Variations	Mar. 1948
2	Trafficability Studies, Fort Churchill, Summer 1947	Aug. 1948
3	Development of Testing Instruments	Oct. 1948
4	Tests on Self-Propelled Vehicles, Yuma, Arizona, 1947	Apr. 1949
5	Analysis of Existing Data	May 1949
6	Tests on Self-Propelled Vehicles, Vicksburg, Miss., 1947	Sept. 1949
7	Tests on Towed Vehicles, 1947-1948	June 1950
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9	Vehicle Classification	May 1951
10	Tests on Natural Soils with Self-Propelled Vehicles, 1949-1950	Jan. 1954
11	Soil Classification	Aug. 1954
12	Tests on Natural Soils with Self-Propelled Vehicles, 1951-1953	Nov. 1954
13	Pilot Study, Tests on Coarse-Grained Soils	Nov. 1955
14	A Summary of Trafficability Studies Through 1955	Dec. 1956
15	Tests on Coarse-Grained Soils with Self-Propelled and Towed Vehicles, 1956 and 1957	June 1959
16	Soil Classification	Aug. 1961
17	Tests on Coarse-Grained Soils with Self-Propelled and Towed Vehicles, 1958-1961	May 1963
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19	Effects of Surface Conditions on Drawbar Pull of a Wheeled Vehicle	Apr. 1971

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13. ABSTRACT Tests were conducted with one wheeled vehicle to determine effects of soil surface conditions on drawbar pull and to relate optimum drawbar pull to soil strength as measured by a number of instruments. One hundred and six drawbar pull-slip tests were conducted with an M37 3/4-ton truck at a gross weight of 7240 lb. One tire size (9.00-16, 8-PR), two tread patterns (smooth and nondirectional military), and two tire deflections (15% and 35%) were tested. Surface conditions varied from dry and firm to wetted with small amounts of water to flooded. Asphalt surfaces also were tested. Measurements of soil strength were made with the standard cone penetrometer, multiprobe penetrometer, sheargraph, soil truss, and friction wheel. Analysis of data indicated that the multiprobe penetrometer and sheargraph show the most promise as instruments for measuring surface conditions and predicting vehicle performance. Equations were developed for predicting drawbar pull based on deflection and soil measurements with the sheargraph and multiprobe penetrometer.

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by

E. S. Rush, J. H. Robinson

April 1971

Sponsored by U. S. Army Materiel Command
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Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

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FOREWORD

The study reported herein was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) in furtherance of Department of the Army Research and Development Project 1T062103A046, "Trafficability and Mobility Research," Task 02, "Surface Mobility." This project is under the sponsorship and guidance of the Research, Development, and Engineering Directorate, U. S. Army Materiel Command.

Field tests were performed intermittently over a four-year period (1966-1969) by personnel of the Vehicle Studies Branch (VSB), Mobility and Environmental (M&E) Division, under the direction of Messrs. B. G. Schreiner and J. H. Robinson. The report was prepared by Messrs. E. S. Rush and J. H. Robinson. Personnel of the M&E Division in general supervisory capacity were Messrs. W. G. Shockley and S. J. Knight, Chief and Assistant Chief, respectively, of the division, A. A. Rula, Chief, VSB, and E. S. Rush, Engineer, VSB.

Directors of the WES during the test program and preparation of this report were COL John R. Oswalt, Jr., CE, COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE. Technical Directors were Messrs. J. B. Tiffany and F. R. Brown.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
yards	0.9144	meters
miles (U. S. statute)	1.609344	kilometers
square inches	6.4516	square centimeters
pounds	0.45359237	kilograms
tons (2000 lb)	907.185	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
pounds per cubic foot	16.0185	kilograms per cubic meter
inch-pounds	0.011521	meter-kilograms

SUMMARY

A study was conducted to (a) investigate the effects of soil surface conditions on one-pass drawbar pull capabilities of a wheeled vehicle, (b) relate optimum drawbar pull to soil strength as measured by several instruments, (c) develop tentative equations for predicting optimum tractive coefficient, and (d) determine effects of tire characteristics (tread pattern and deflection) on drawbar pull. One hundred and six drawbar pull-slip tests were conducted with a 3/4-ton M37 truck at a gross weight of 7240 lb. One tire size (9.00-16, 8-PR), two tread patterns (smooth and nondirectional military), and two tire deflections (15% and 35%) were tested. Surface conditions varied from dry and firm, to wetted with small amounts of water, to flooded. Asphalt surfaces also were tested.

Measurements of soil strength were made with the standard cone penetrometer, multiprobe penetrometer, sheargraph, soil truss, and friction wheel. Optimum tractive coefficient (opt TC), an index of maximum work output during a specific drawbar pull-slip test, was used as the measure of vehicle performance for all tests. Using the opt TC values for analysis instead of a maximum TC value at a selected slip value eliminated the problem of determining the maximum TC value in cases where the drawbar-slip curves showed a gradual increase in pull with increased slip through the entire range of slip. In most tests, however, maximum TC and opt TC were nearly the same.

Data were insufficient to determine quantitatively the effects of surface cover, soil type, etc., on opt TC. Qualitatively, however, different surface conditions did affect opt TC in that dry, firm surfaces yielded the highest opt TC values, but when these surfaces were sprinkled with water, flooded, or covered with mud, opt TC values were reduced considerably.

Analysis of data indicates that the multiprobe penetrometer and the sheargraph show the most promise as instruments for measuring surface conditions for predicting surface traction. Based on multiprobe measurements at the 1/4-in. soil depth ($MPI_{1/4}$), the following equation was developed for predicting opt TC for treaded tires:

$$\text{opt TC} = 0.04 \times \text{decimal deflection}^{0.195} \times MPI_{1/4}^{0.545}$$

Based on sheargraph values (S_r), the following equations were developed for predicting opt TC for both treaded and smooth tires:

Treaded tires

$$\text{opt TC} = 0.265 \left[(\text{decimal deflection} \times S_r)^{0.815}\right]$$

Smooth tires

$$\text{opt TC} = 0.265 \left[(\text{decimal deflection} \times S_r) - 0.47\right]^{0.815}$$

A comparison of measured opt TC and opt TC predicted using the three equations listed above showed that, on the average, 62% of the data points were within ± 0.10 opt TC of the 1:1 line. The overall average deviation was 0.12 opt TC.

In most tests for the same test conditions and deflections, treaded tires developed higher pulls than smooth tires except for tests on sand. For the same test conditions and tread patterns, higher pulls were developed with tires at 35% deflection than at 15% deflection except for tests on pavement and a few tests on dry, bare surfaces.

TRAFFICABILITY OF SOILS

EFFECTS OF SURFACE CONDITIONS ON DRAWBAR PULL OF A WHEELED VEHICLE

PART I: INTRODUCTION

Background

1. Studies concerned with the development of relations between natural-surface media and vehicle mobility have been conducted for a number of years. The ultimate objective of these studies is to develop a general set of mathematical expressions that adequately relate the effects of surface media on pertinent vehicle performance parameters. Performance parameters considered include ability to go, drawbar pull, motion resistance, speed, and maneuverability. Surface media thus far investigated have been fine-grained soils, coarse-grained soils (sand), organic terrain (muskeg), and snow. For the most part, it has been determined that these four media react differently to vehicles operating over them; therefore, for the present they are being considered separately. Fine-grained soils are currently receiving the greatest attention in vehicle mobility research.

2. Previous studies in fine-grained soils have emphasized development of performance criteria on a 50-pass* basis. This work is essentially complete and has been reported in numerous U. S. Army Engineer Waterways Experiment Station (WES) technical reports and papers. Current emphasis is being placed on development of one-pass criteria, and two reports related to one-pass performance have been published.** These reports indicate the need for additional study.

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* Fifty trips of a vehicle over the same straight-line path.

** U. S. Army Engineer Waterways Experiment Station, CE, "One-Pass Performance of Vehicles on Fine-Grained Soils," by C. J. Nuttall, Jr., C. W. Wilson, and R. A. Werner, Contract Report 3-152, July 1966, and "A Study of the Effects of Wet Surface Soil Conditions on the Performance of a Single Pneumatic-Tired Wheel," by J. L. Smith, Miscellaneous Paper No. 4-757, Nov 1965, Vicksburg, Miss.

3. Presently two different soil conditions are being studied in the development of a system for predicting one-pass vehicle performance. One condition is a deep soft soil (low soil mass strength) that permits appreciable vehicle sinkage, and the other condition is firm soil with a thin, soft surface layer that causes low vehicle traction but no (or little) sinkage. This report is concerned with the latter condition.

Purpose and Scope

Purpose

4. The general purpose of this study was to investigate the effects of surface conditions on the one-pass drawbar pull of a wheeled vehicle. The specific purposes were to: (a) relate measurements of drawbar pull (optimum tractive coefficient) to measurements of surface soil strength made with a variety of instruments; (b) develop tentative equations for predicting optimum tractive coefficient; and (c) determine effects of tire characteristics (tread pattern and deflection) on drawbar pull.

Scope

5. One hundred and six drawbar pull-slip tests were conducted with a 3/4-ton* M37 truck having a gross weight of 7240 lb. One tire size (9.00-16, 8-PR), two tire patterns (nondirectional military tread and smooth), and two tire deflections (15% and 35%) were tested. Three soil types (clay, silt, and sand) were tested. Surface conditions varied from dry and firm to wetted with small amounts of water to flooded. A few tests were conducted on firm soil overlaid with soft, viscous soil that varied in thickness from about 1/2 in. to about 4 in. Asphalt surfaces also were tested.

Definitions

6. Most of the terms used herein have been defined in standard texts and glossaries of trafficability reports. Special terms will be defined as they occur in this report.

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* A table of factors for converting British units of measurement to metric units is presented on page ix.

PART II: TEST PROGRAM AND DATA REDUCTION

Location and Description of Test Areas

7. The drawbar pull-slip tests were conducted on the WES reservation, Vicksburg, Miss.; at Hicks' farm in Louisiana, approximately 7 miles west of Vicksburg; on an unsurfaced road of fat clay near the Sunflower River diversion canal approximately 8 miles north of Vicksburg; and on the west bank of the Mississippi River near the bridge at Vicksburg. Summaries of soil properties and surface conditions are given in table 1. Soils were classified according to the Unified Soil Classification System (USCS). Each test area is described briefly in the following pcragraphs.

WES Reservation

8. Tests at WES were conducted at five different sites: an asphalt roadway, a prepared test lane in the stress building, a prepared test lane in hangar 4, an upland silt area, and a natural bottomland silt area.

9. Asphalt roadway. Fig. 1 shows the level asphalt roadway test site.

Fig. 1. Asphalt roadway test site at WES

10. Stress building. Fig. 2 shows a section of the lane in the stress building. The lane was prepared from a fat clay (CH) soil and was

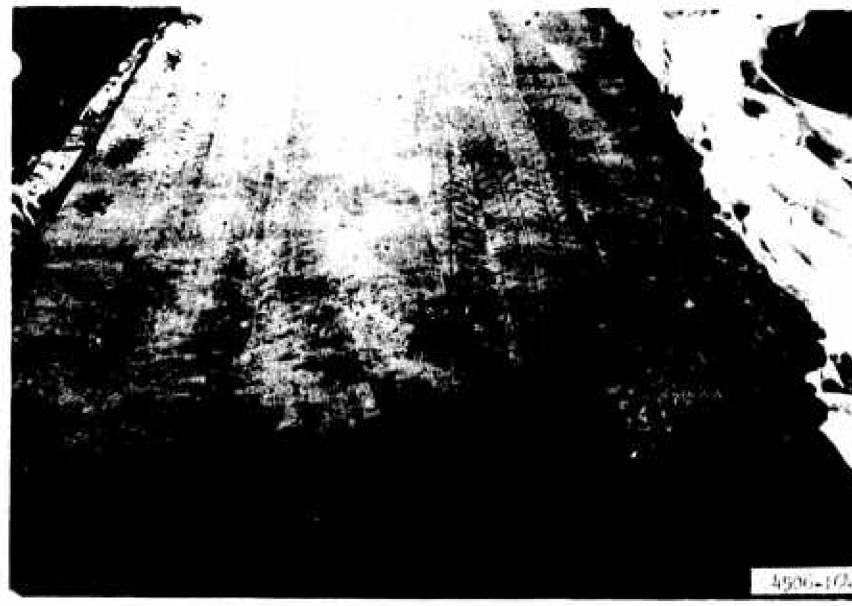

Fig. 2. Section of prepared test lane in stress building

12 in. deep, 14 ft wide, and 70 ft long. Lane preparation will be described later. Because the prepared lane was under shelter, it could be preserved for extended periods.

11. Hangar 4. Fig. 3 shows a section of the test lane in hangar 4. Tests were performed at this location to take advantage of a fat clay (CH) lane that had been prepared for another study.

Fig. 3. Section of prepared test lane in hangar 4

12. Upland flat. Fig. 4 shows the upland flat test area. Soils in this area were a silt (ML) and a lean clay (CL), and were covered with grass at the time of testing. Tests were begun on a natural soil surface, but as testing progressed, the surface was modified as described later.

Fig. 4. WES upland flat test site

13. Bottomland flat. Fig. 5 shows a section of the bottomland flat test site. One segment of the area was dry and firm; the other was periodically flooded and a layer of soft silt (ML) of varying thickness had been deposited over residual firmer silt soil. Grass cover ranged from none to approximately 25%; height of grass was from 2 to 5 in.

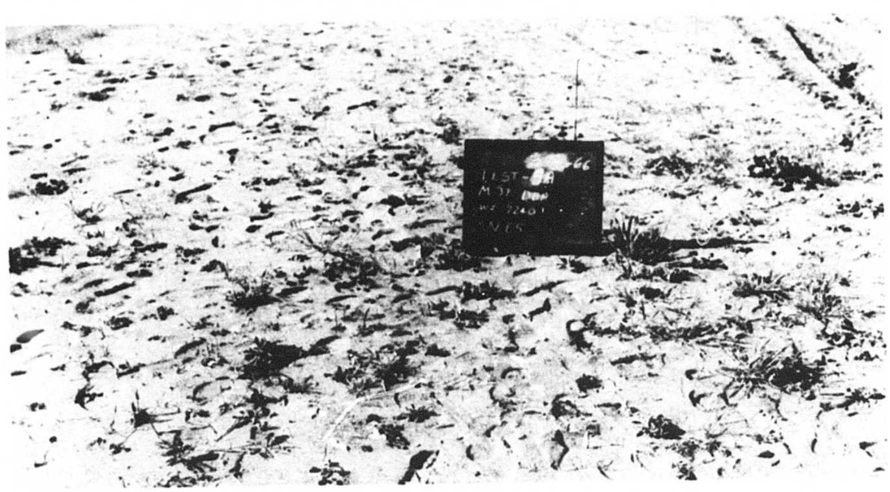

Fig. 5. Section of WES bottomland flat test site

Hicks' farm

14. Tests were conducted in a fat clay (CH) test lane at Hicks' farm (fig. 6). The lane was first tested in its natural condition; i.e. the surface was covered with 0.5-in.-high grass. Thereafter, the surface was prepared as described later.

Fig. 6. Hicks' farm

Sunflower canal road

15. Fig. 7 shows the Sunflower canal test road. This road was level and constructed of in situ fat clay (CH) soil. Local traffic had created indentations that tended to channel the test vehicle along distinct lanes. The road was first tested in its natural state; thereafter, the surface was changed as described later.

Fig. 7. Sunflower canal road

Mississippi River

16. Fig. 8 shows the Mississippi River test area. Tests were conducted on clean sand (SP) of various moisture contents, depending upon the distance of the lanes from the water's edge.

Fig. 8. Test site on bank of Mississippi River

Test Lane Preparation and Test Sequences

Stress building

17. The test lane in the stress building was constructed in an excavated 12-in.-deep pit. The pit had been backfilled with fat clay soil processed to a predetermined moisture content that was favorable for compaction and for smoothing the surface. Soil was placed in the pit in approximately 4-in. lifts and compacted with a rubber-tired roller. The surface of each lift was scarified for better bonding with each succeeding lift. Each lift was compacted until a soil strength of at least 150 cone index (CI) was obtained. After the final lift was compacted, the surface was leveled and smoothed with a wide steel wheel roller. The test lane was then allowed to cure for a specified time. Curing of the prepared soil permitted the moisture in the soil to become evenly distributed throughout the mass. During the curing process, the test lane was covered with a waterproof membrane.

18. After construction of the lane was completed, drawbar pull-slip

tests were performed in the lane on four surface conditions: dry, smooth, firm, as built; after flooding and draining; flooded; and after a layer of soft, viscous soil had been placed over the firm surface. After completion of tests on each surface condition mentioned above, that portion of the surface affected (contaminated) either by wheels of the test vehicle or by the surface treatment was removed so that each new surface or test condition started with a firm, dry smooth surface as similar as possible to the original surface.

Hangar 4

19. The test lane in hangar 4 was constructed of fat clay soil compacted to a CBR of 9 (equivalent to approximately 450 CI). It previously had been used as a base for landing mat tests. The surface was leveled with a motor patrol and rolled smooth with a steel wheel roller, then lightly sprinkled with water prior to the drawbar pull-slip tests.

Upland flat

20. Drawbar pull-slip tests were conducted on both natural and prepared surfaces in the upland flat area. The natural surface cover ranged from 30% to 100% of 2- to 14-in.-high grass. Tests were conducted on all the grass-covered areas while the surface was dry and on the 100% grass-covered surface after sprinkling with water. For the prepared surface the grass was removed with a motor grader and the surface was compacted with a steel wheel roller. Tests were conducted while the surface was dry, after sprinkling the surface with water, and after flooding. Following tests on each surface condition, the contaminated surface was removed with the motor grader and the new surface was rolled smooth before the next test or surface preparation. Surface CI of the dry, natural test lane was 287 (test A-10) and of the dry, prepared test lane was 417 (test A-17).

Bottomland flat

21. This flat was actually a hydraulic fill, but for purposes of the tests was considered to be natural soil since no preparations were made prior to testing. Surface CI's ranged from 11 (test A-13) to 111 (test A-8), and surface cover ranged from none to 25% of 2- to 3-in.-high grass. All tests were conducted on the natural surface.

Hicks' farm

22. Drawbar pull-slip tests were conducted on the natural grass surface. Then the test lane was prepared for each bare surface condition in a manner similar to that of the upland flat test area. Tests were conducted on the following surface conditions: dry, flat, firm surface with 35% surface cover of 0.5-in.-high native grass; the same surface after it had been sprinkled with water; a dry, smooth, firm surface bare of vegetation; and the same bare surface after it had been sprinkled with water.

Sunflower canal road

23. Tests were conducted in this test area on the following surface conditions: dry, firm surface; firm surface after it had been sprinkled with water; and surface after it had been wetted by natural rainfall.

Mississippi River sand beach

24. Tests were conducted on natural, level beach surfaces. Three test locations were selected that provided three moisture conditions--dry, moist, and wet. Cone indexes at the surface were: 28 (test AS-29) for dry sand; 32 (test AS-31) for moist sand; and 24 (test AS-33) for wet sand.

Test Vehicle and Performance Measurements

25. The test vehicle was a standard 3/4-ton M37 truck similar to the one shown in fig. 9. Two sets of 9.00-16 tires were tested at two tire deflections. One set of tires had standard military nondirectional treads (fig. 10), and the other set was the same type of tire except that the treads had been removed (fig. 11). The vehicle was loaded so that the wheel loads were the same for all test conditions. Pertinent tire data are given in the following tabulation:

Tire	Deflection, %	Inflation Pressure psi	Contact Area per Wheel sq in.	Wheel Load lb	Contact Pressure psi
Treaded	15	39.1	56.8	1810	31.9
	35	13.4	107.7	1810	16.9
Smooth	15	38.3	44.0	1810	41.1
	35	10.4	105.5	1810	17.1

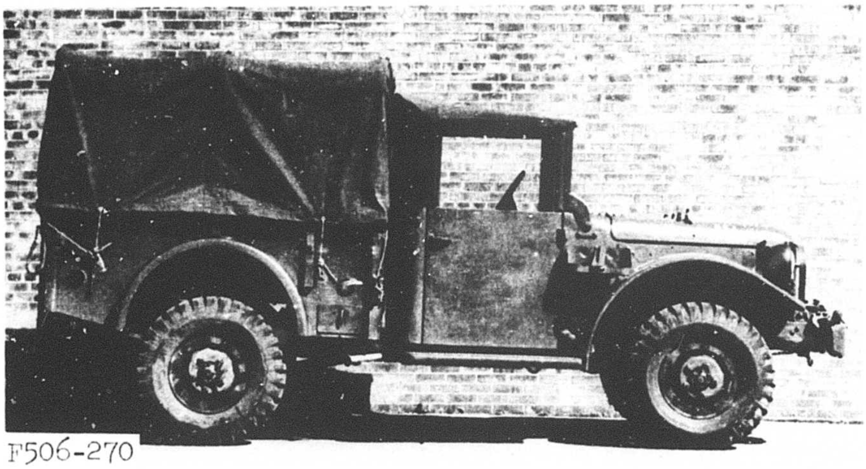

Fig. 9. M37 3/4-ton truck

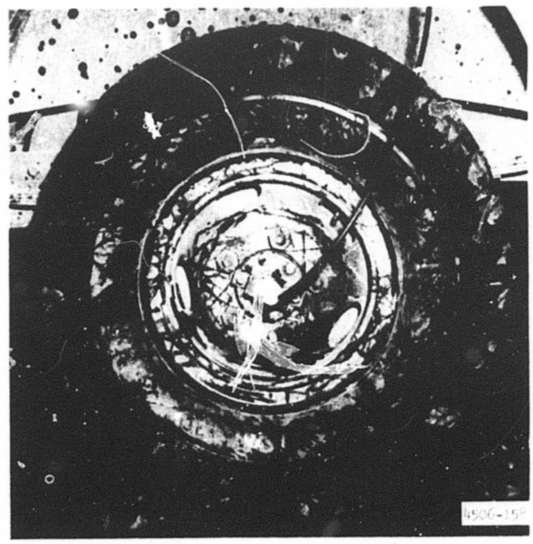

Fig. 10. Standard nondirectional tread tire

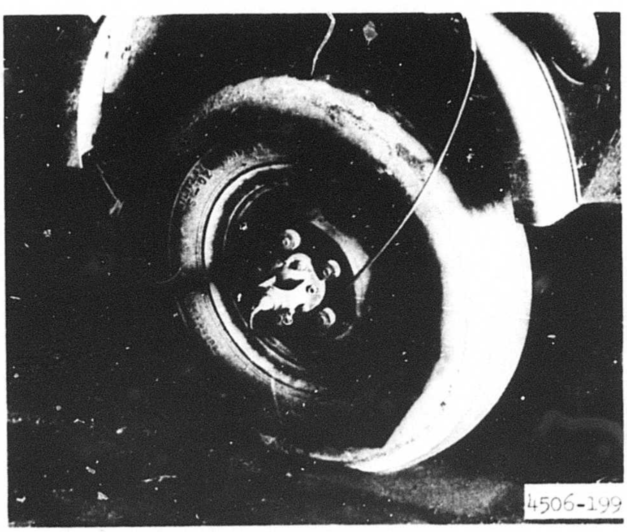

Fig. 11. Smooth tire

26. The contact areas were measured from tire prints on a hard, unyielding surface. Interruptions of the contact area due to tread patterns were considered part of the contact area of the treaded tire. Deflection is defined as follows:

$$\text{Percent deflection} = \frac{\text{unloaded carcass section height* minus loaded carcass section height}}{\text{unloaded carcass section height}} \times 100$$

27. Instruments were installed on the test vehicle to obtain a continuous record of drawbar pull, driveline torque, wheel distance traveled by all wheels, and vehicle distance traveled. Rut depths were measured with rod and level after each test. A summary of vehicle performance data is given in table 2.

Determination of Soil Strength Values

28. A summary of soil strength data obtained with various instruments is given in table 3; the devices and methods used to determine soil strength and the data reduction procedures are described below.

Cone penetrometer

29. Soil strengths were measured with a standard hand-operated penetrometer similar to that used in soil trafficability studies (fig. 12) and a recording penetrometer. The recording penetrometer most used in these tests is shown in fig. 13; it is a hand-operated device. Another recording penetrometer with cone and shaft mounted in a movable test carriage (shown in fig. 14) was used in the stress building.

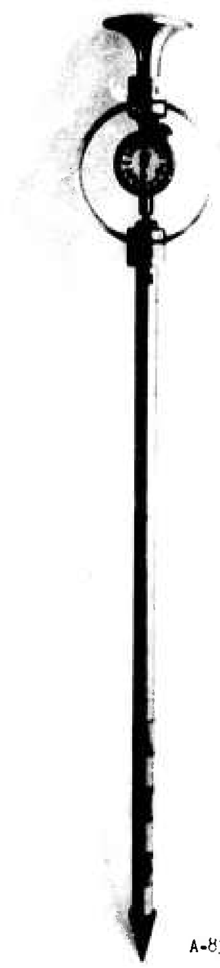

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Fig. 12. Standard cone penetrometer

30. Standard penetrometer. Soil strengths were measured with a standard penetrometer having a 30-deg apex angle cone with a base area of 0.5 sq in. mounted

* Smith, op cit, p 1.

Fig. 13. Hand-operated recording penetrometer

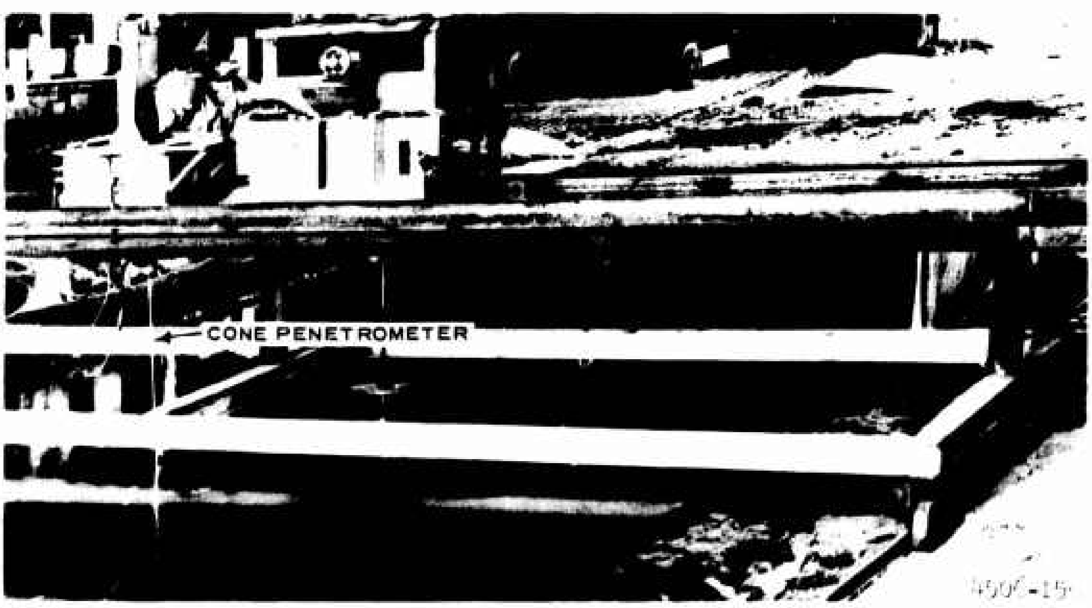

Fig. 14. Penetrometer mounted on test carriage

on a 0.625-in.-diam shaft, or with a base area of 0.2 sq in. mounted on a 0.375-in.-diam shaft. The value obtained by dividing the force (in pounds) required to cause the cone to penetrate the soil by the base area (in square inches) of the cone is an index that reflects the shear resistance of the soil. Cone indexes (CI) were read from the dial gage when the cone base penetrated the surface and when it passed each inch increment to the 6-in. depth unless penetration resistance was greater than the capacity of the instrument. Maximum vertical load capacity of the instrument was 300 CI for the 0.5-sq-in. cone and 750 CI for the 0.2-sq-in. cone. The readings were obtained at a penetration rate of about 6 fpm. Average CI values for each depth are shown in table 3.

31. Recording penetrometers. The recording penetrometer used for all soil strength measurements except those made in the stress building employed the standard penetrometer shafts and cones, but the proving ring and dial gage assembly were replaced with a load cell for electrically measuring the vertical force applied to the penetrometer handle and a linear potentiometer for electrically measuring depth of penetration. Vertical load capacity and penetration rates were about the same as those for the standard penetrometer. Continuous records of CI's and penetration depth were made with an X-Y recorder. Fig. 15 shows examples of recordings for four penetrations made at one location on the test lane of test S-13. Twenty penetrations along each test lane were recorded and values shown in table 3 for a given test are the average of values read from the traces on the X-Y recorder.

32. In the stress building, data recordings, number of penetrations made, and data reductions were similar to those described in the preceding paragraph. However, it will be recalled that the standard shaft and cone of the penetrometer were mounted in a movable test carriage. The test carriage moved on rails mounted at the sides of the test lane. Downward force of the penetrometer was measured with a load cell; depth of penetration was indicated by precalibration of the gear mechanism that moved the shaft and cone downward.

Multiprobe penetrometer

33. The multiprobe penetrometer measurements were performed with the

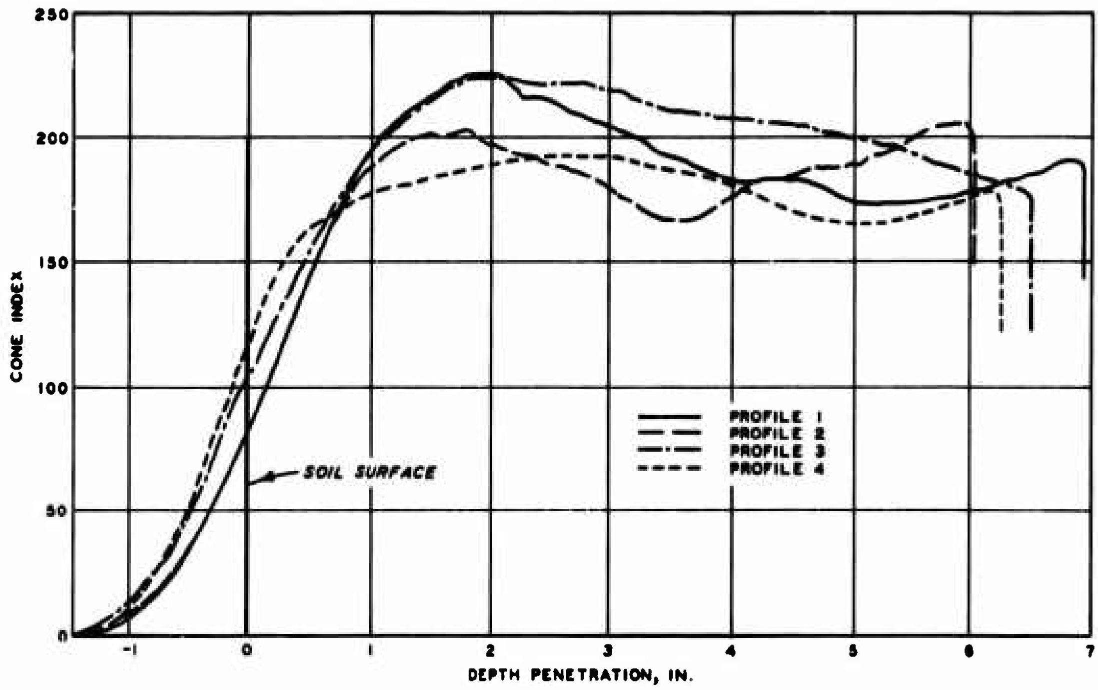

Fig. 15. Profiles obtained with hand-operated recording penetrometer, test S-13

device shown in fig. 16. The device can be used on standard penetrometer shafts by simply replacing the cone with the multiprobe plate. Penetration was limited to a maximum of 1.75 in. below the surface, which was the height of the individual probes. The probe tips had a total base area of 0.5 sq in. Nine individual probes, each with a tip diameter of 0.266 in. (area of 0.056 sq in.), were uniformly spaced in the base plate. The individual probe stems were smaller in diameter (0.125 in.) than the tips to minimize stem-soil friction during penetration. For this program the measurements were made and recorded and data reduced in the same manner as that for the recording penetrometer. Multiprobe index (MPI) values are shown in table 3. Values were read from the recorder traces at 1/4-in. vertical intervals from 1/4 in. below the surface to a depth of 1-3/4 in.

<u>Cohron sheargraph</u>

34. Soil strengths were determined with the Cohron sheargraph (fig. 17), a hand-operated shear device utilizing a coiled helical spring system for measuring axial and rotational forces. Several different shear heads are available for this device, but the two used in this study were a vaned

Fig. 16. Multiprobe penetrometer

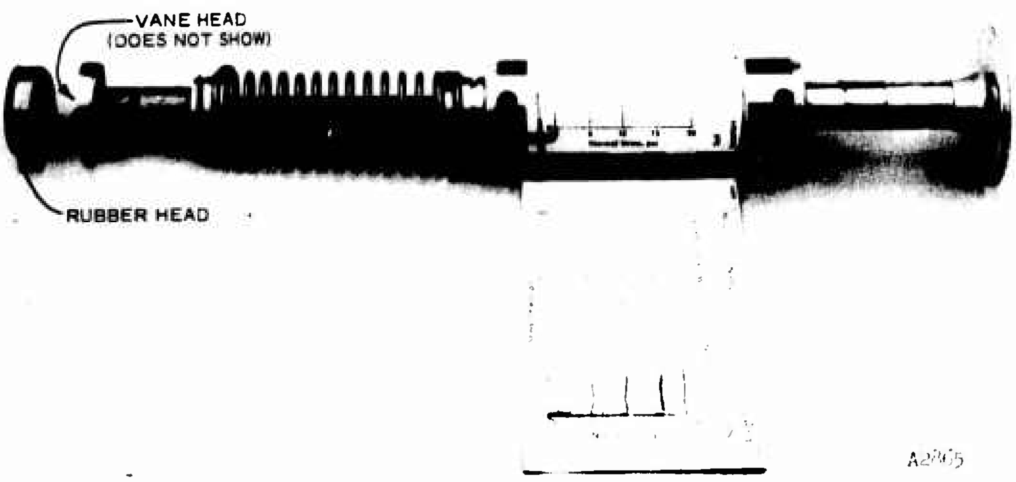

Fig. 17. Cohron sheargraph

head and a smooth, rubber-coated head, both of 2-sq-in. end area. One end of the spring is attached to the shear head and one to a metal stylus. The stylus responds to the yielding of the helical spring in both the vertical direction and in torsion, and it traces the response onto pressure-sensitive graph paper mounted in a drum attached to the handle of the instrument. Selected normal stresses up to 20 psi (approximate capacity) are applied to the handle and the instrument is rotated until shear failure occurs in the soil. Shear failure may be abrupt with the vaned shear head, but usually it is gradual with the rubber head. Linear relations of best visual fit for shear stress (approximating peak shear) versus normal stress were developed from the sheargraph charts (approximately 10 charts per test lane were obtained). These relations were used to obtain values for the effective adhesion (a_r for rubber head), effective cohesion (c_v for vaned head), and internal friction angle (ϕ) (shown in table 3 as tan ϕ for ease of computation) of the soil being tested. Shear stress values (S_v for vaned head and S_r for rubber head) were then computed for the contact pressure N of the vehicle by Coulomb's equation:

$$S_v = c_v + (N \tan \phi_v)$$

$$S_r = a_r + (N \tan \phi_r)$$

For example, in test S-1 (table 3) $c_v = 14.9$ and $\tan \phi_v = 0.454$, and $N = 31.9$ (from paragraph 25, treaded tires, 15% deflection); therefore

$$S_v = 14.9 + (31.9 \times 0.454) = 29.4$$

For contact pressures at 15% deflection (31.9 psi for treaded tires and 41.1 psi for smooth tires), extrapolations of stress-strain curves were necessary to obtain data points for correlation purposes because the maximum normal stress capacity of the sheargraph was 20 psi.

Mark II soil truss

35. The Mark II soil truss (fig. 18) was designed by the U. S. Naval Civil Engineering Laboratory to obtain measures of the effective

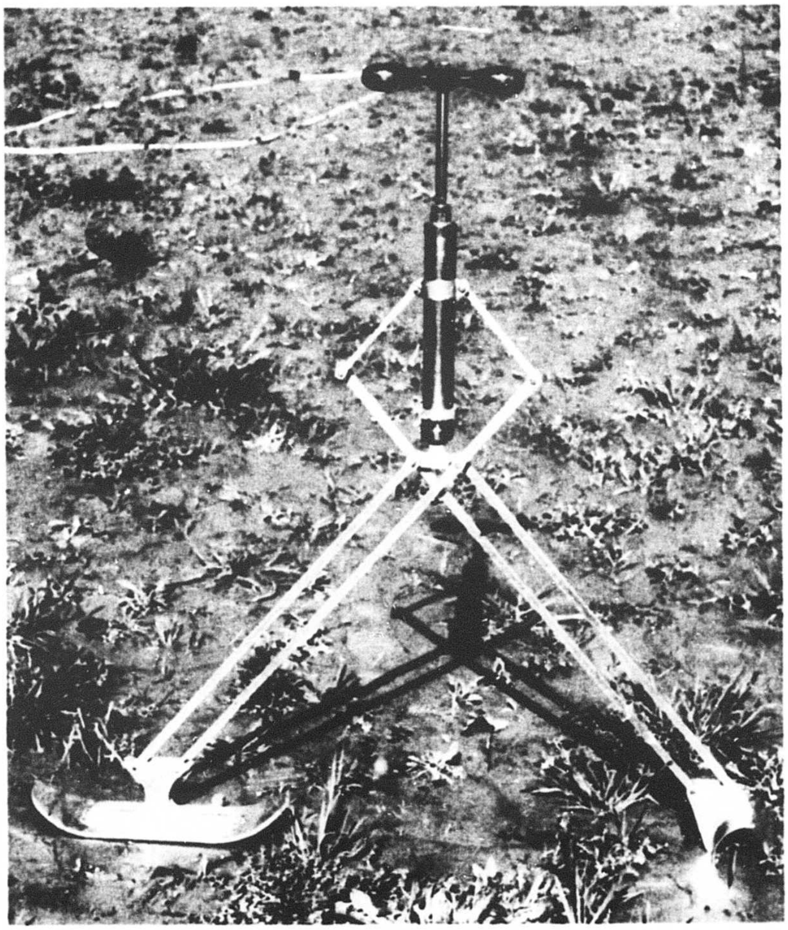

Fig. 18. Mark II soil truss with rubber-coated ski

coefficient of cohesion and the effective angle of internal friction of in situ surface soils. The instrument consists of two pivotal legs attached to a collar that operates vertically on a calibrated loading cylinder. Application of a vertical force on the cylinder is transferred through normal and shearing components to an anchored shoe on one leg and to a shear device on the other leg. By attaching one of several specially designed rubber-coated skis (shoes) or center-load tare (shear box) shear devices, the soil surface can be made to shear horizontally when load is applied vertically on the handle. Normal load range is between about 10 and 110 lb. The legs may be set at angles between 30 and 60 deg. For a given test condition in this study, at least five measurements were made of shear at different combinations of loads and leg angles. The load and angle readings

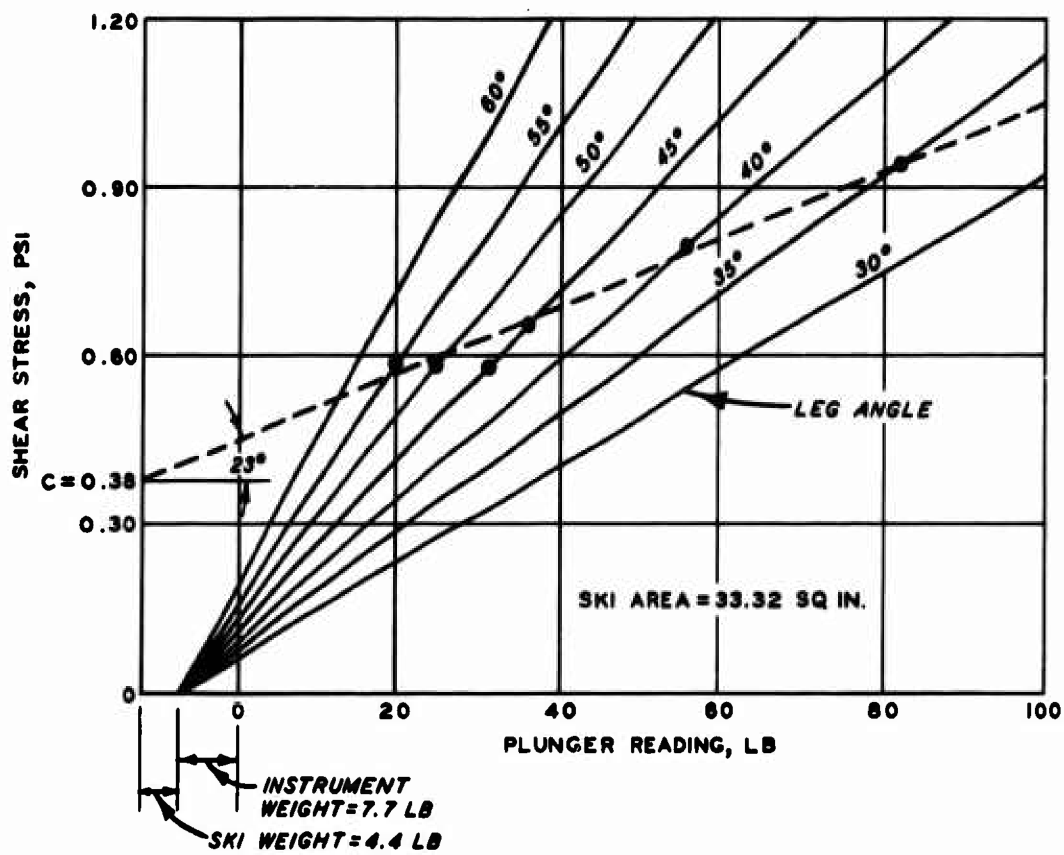

Fig. 19. Field chart for soil truss with large rubber ski, data from test S-13

were then transferred to field charts, a sample of which is shown in fig. 19. A line of best fit was drawn through the measured data points to develop the envelope of failure for the particular soil condition tested. Measures were then obtained of effective adhesion (a_s) for the rubber ski, effective cohesion (c_t) for the center-load tare, and angle of internal friction (ϕ). Tan ϕ values instead of angle values are shown in table 3 for convenience when computing shear stress values. Shear stress values (S_s for rubber ski and S_t for center-load tare) were computed for contact pressure N of the vehicle by Coulomb's equation:

$$S_s = a_s + (N \tan \phi_s)$$

$$S_t = c_t + (N \tan \phi_t)$$

For example, in test P-1 (table 3) $a_s = 0$ and $\tan \phi_s = 0.810$, and $N = 31.9$ psi (paragraph 25, treaded tires, 15% deflection); therefore

$$S_s = 0 + (31.9 \times 0.810) = 25.8 \text{ psi}$$

Friction wheel

36. Soil strength measurements were made with the friction wheel shown in fig. 20. This device was designed to measure the shear resistance

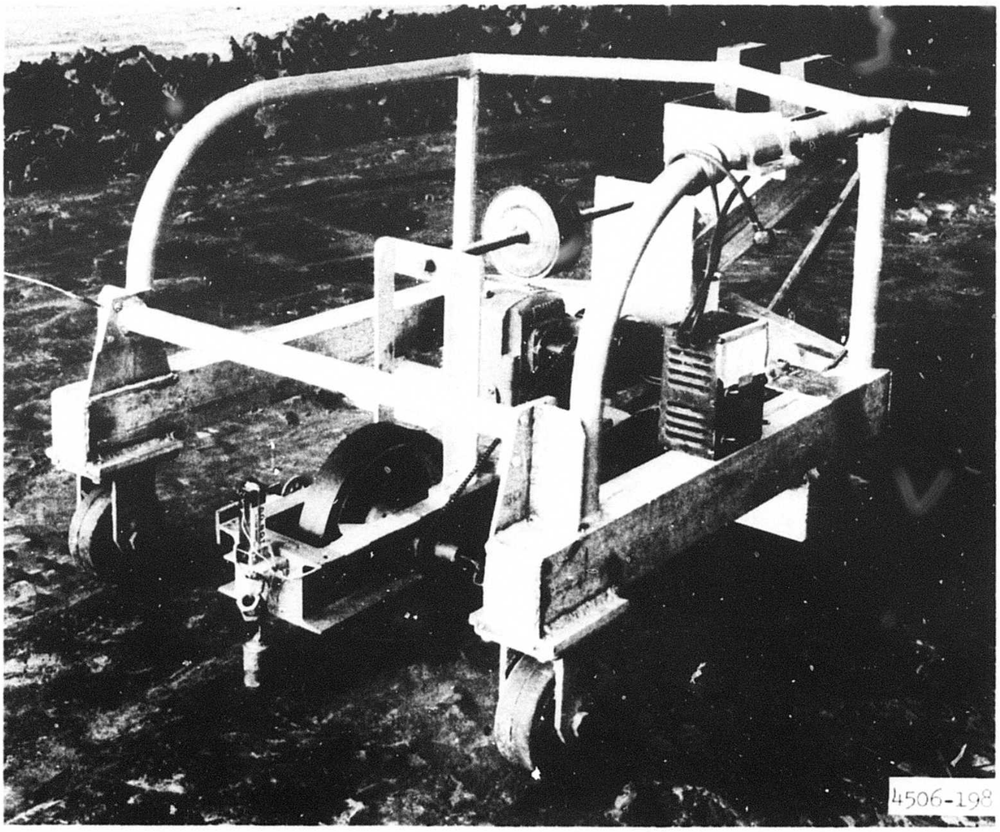

Fig. 20. Friction wheel

of in situ soil produced by the rotation of a smooth, hard, rubber wheel 11.818 in. in diameter and 2 in. wide.* The friction wheel was originally mounted in a stationary frame for laboratory use, but for this study it was

* M. P. Meyer, "Comparison of Engineering Properties of Selected Temperate and Tropical Surface Soils," Technical Report No. 3-732, June 1966, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

mounted in a portable frame for field use. The wheel was attached to a counterbalanced beam center pivoted so that the wheel could be made to just touch the soil surface (zero load on the wheel) for calibration purposes, and a desired constant vertical load could be applied during testing. During the tests, measurements were made of torque, angular displacement, and sinkage of the wheel during two revolutions (720 deg). These measurements were made with wheel loads of 5, 20, and 35 lb and were electrically recorded on an X-Y recorder. For a given test lane at least eight measurements were made with each wheel load. A sample of test results is shown in fig. 21 for a 35-lb load in test S-2. By combining three test parameters

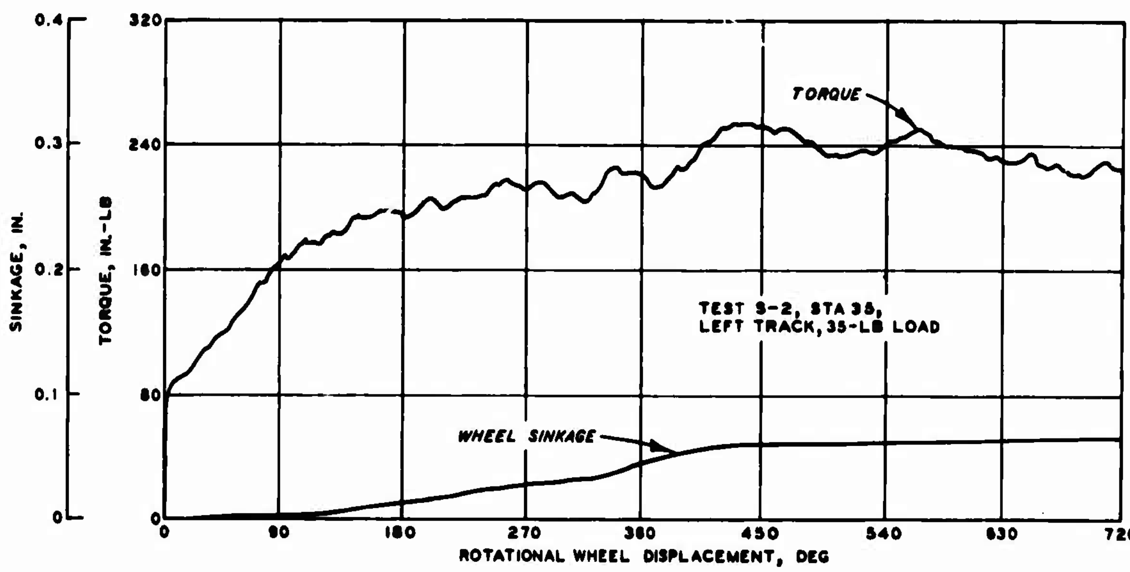

Fig. 21. Example of friction wheel record trace

(torque, radius of wheel, and contact area of wheel), an index of the shear strength (traction index, TI) of the soil measured by the rotating wheel was computed for each load using the following equation:

$$\text{TI (psi)} = \frac{\text{torque (in.-lb)}}{\text{radius of wheel (in.)} \times \text{contact area (sq in.)}}$$

where

contact area = width of the wheel (2 in.) × the arc length of the wheel in contact with the soil after 720-deg rotation

torque = average for 720-deg rotation

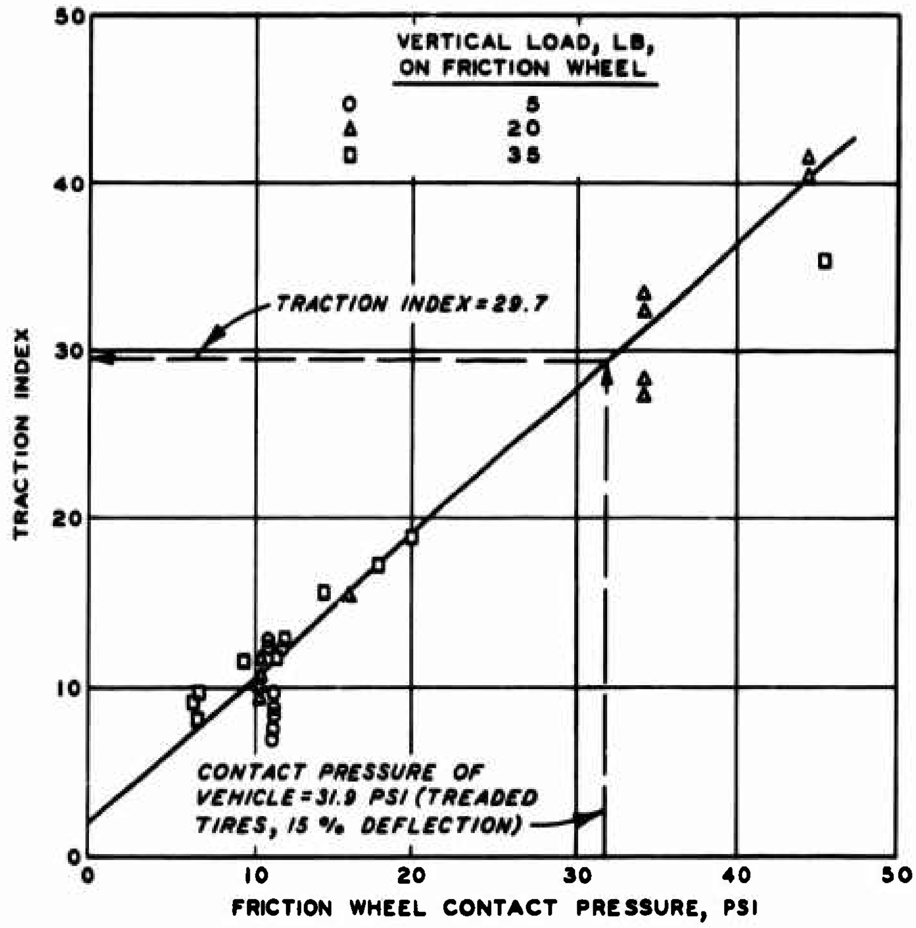

Fig. 22. Stress building test S-2. Friction wheel contact pressure versus traction index

37. A plot was then made of friction wheel contact pressure (varies with load and sinkage as well as torque) for each test (fig. 22 shows results of test S-2). To obtain TI for the test, a line of best fit was drawn through the data points and TI was read from the line at the contact pressure of the vehicle.

Optimum Tractive Coefficient (Opt TC)

38. The drawbar pull-slip curves that were developed in this study had many different shapes. It was desirable to select a drawbar pull value for each test that, by definition, would be consistent for all tests and that could be used to establish correlations with soil strength as measured

by the various measuring devices. The value selected, opt TC, is based on criterion of maximum work output (WOC) during a specific drawbar pull-slip test. A WOC curve is developed from the tractive coefficient (TC) slip curves as shown in the example in fig. 23. The slip at which maximum WOC

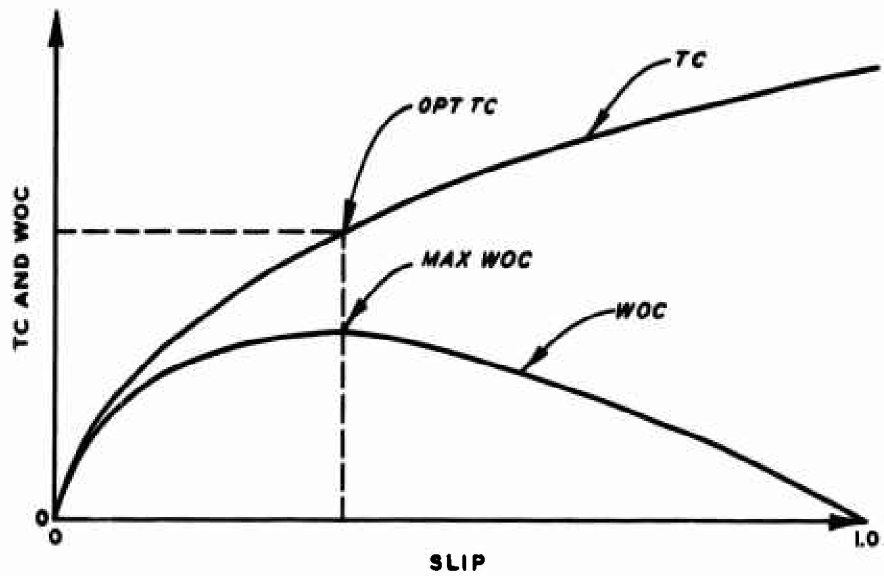

Fig. 23. TC and WOC versus slip

occurs is termed optimum slip and the tractive coefficient at this slip is termed opt TC. WOC is an arbitrary index of efficiency defined as the ratio of "work output" to "work input" where work output is drawbar pull (D) times the distance the vehicle travels (S) in the time interval (t) and work input is the weight of the vehicle (W) times the distance the wheels travel (L) in the same time interval (t), or

$$WOC = \frac{D(S/t)}{W(L/t)}$$

and since

$$\frac{D}{W} = TC$$

and

$$slip = 1 - \frac{S/t}{L/t}$$

or

$$\frac{S/t}{L/t} = 1 - slip$$

then

$$WOC = TC\ (1 - slip)$$

PART III: ANALYSIS OF DATA

39. Analysis of data consisted of: (a) a presentation of drawbar pull-slip data and the average curve for each test, (b) correlations between opt TC and soil strength measurements made with each of the several instruments, and (c) a study of the effects of surface conditions, tire treads, and deflections, respectively, on opt TC and slip.

Drawbar Pull-Slip Tests

40. Drawbar pull-slip data points and average curves for each test are shown in plates 1-14. For a given test condition data were plotted on the basis of tires with and without treads and 15% and 35% deflections. In some cases the data points between 80% and 100% slip indicate sharp increases in pull when compared with pulls at lesser slips. This probably occurred when the tires dug through wet surface layers and gained traction on firm soil beneath. In these tests the average curves at the high slips are shown as dashed lines. The number of the plate in which the test data for each test area are plotted is tabulated below. Tests are discussed in the following paragraphs in order of area location.

Test Area	Plate No.
WES Reservation	
Asphalt roadway	1
Stress building	2-5
Hangar 4	6
Upland flat (natural surface)	7
Upland flat (prepared surface)	8
Bottomland flat	9
Hicks' farm	10-12
Sunflower canal road	13
Mississippi River sand beach	14

WES Reservation

41. Asphalt roadway. Four tests were conducted on the asphalt roadway (plate 1). For all tests opt TC was attained at wheel slips between 12% and 16%. Treaded tires developed higher pulls than smooth tires at the same deflection.

42. Stress building. Twenty-five tests were conducted on prepared surfaces in the stress building (plates 2-5). Results are discussed according to surface conditions in the following subparagraphs.

a. Dry surface. Nine tests were conducted--four with treaded tires at 15% deflection, three with treaded tires at 35% deflection, and one each with smooth tires at each deflection (plate 2). In fig. a, data for three tests (S-1, -2, and -5) could be grouped so that an average curve could be used. However, test S-28 on an apparently similar surface showed drawbar pull-slip characteristics that were different from the other three tests. In fig. b, data for the three tests were very similar and could be grouped so that one average curve represented all three tests.

b. Flooded surface. Four tests with treaded tires were conducted on flooded surfaces (plate 3). Test S-6 at 15% deflection and test S-7 at 35% deflection were conducted on the same flooded surface. Upon completion of these tests, the surface water was drained, the "contaminated" surface soil was removed, and the surface was reflooded. Then tests S-10 and S-11 were conducted on the reflooded surface. Differences in drawbar pull between tests S-6 and S-7 and S-10 and S-11 for the same tire deflection were readily apparent. These differences in drawbar pull were anticipated from soil strengths measured prior to testing. For example, in tests S-6 and S-7 a multiprobe index value of 97 was measured at the 1/4-in. depth whereas in tests S-10 and S-11 a value of 35 was measured (table 3). This difference in soil strength indicates that all of the contaminated surface soil had not been removed between the surface floodings.

c. Drained surface. Four tests were conducted with treaded tires only on drained surfaces (plate 4). These tests followed the tests discussed above on flooded surfaces after surface water had been removed. For example, test S-6 at 15% deflection on the flooded surface was followed by test S-8 at the same deflection on the drained surface condition. As can be seen in plate 4, for the same deflection, differences in pull were experienced between first and second drainings. Again, as in the case of flooded surface tests, the differences in pull were indicated by differences in soil strength although surface treatments were observed to be the same for both drainings.

d. Mud-covered surface. Eight tests were conducted on mud-covered surfaces (plate 5). Mud depths tested were 3, 1, and 3/4 in. Three tests were conducted with treaded tires at 15% deflection, three with treaded tires at 35% deflection, and two tests were conducted with smooth tires, one test each at 15% and 35% deflections. Effects of depth of

mud on drawbar pull were generally as expected, i.e. the deeper the mud, the lower the pull when all other factors were the same. However, drawbar pulls were low (less than about 2000 lb) for all test conditions. Treaded tires developed higher pulls at both tire deflections than smooth tires at either tire deflection. Drawbar pulls with smooth tires were less than about 500 lb at 35% deflection and less than about 200 lb at 15% deflection.

43. Hangar 4, sprinkled surface. Four tests were conducted on the sprinkled surface (plate 6). Two tests were conducted with treaded tires, one test at 15% and one test at 35% deflection; and the same pattern was followed with smooth tires. Treaded tires at both deflections developed more pull than smooth tires at either deflection. For a given tire tread pattern, 35% deflection developed more pull than 15% deflection. Wheel slip at opt TC was high (36% to 40%). Smooth tires at 15% deflection could not pull over 400 lb.

44. Upland areas.

a. Natural grass-covered surfaces. Six tests with treaded tires (four at 15% deflection and two at 35% deflection) were conducted on natural surfaces that varied in grass cover from 30% to 100% (plate 7). Two of the tests were conducted on 100% grass cover after sprinkling with 0.4 in. of water. In fig. a, plate 7, it can be seen that highest pulls were developed on 30% grass-covered surfaces. Data points were scattered such that an average drawbar pull-slip curve was drawn for tests on 70% and 100% grass-covered surfaces. The sprinkled, 100% grass-covered surface (when compared with the same dry surface) had little effect on drawbar pull at either tire deflection except at wheel slips above about 20%.

b. Prepared surface. Fourteen tests were conducted on prepared surfaces on the upland area (plate 8). In each of the four plots, the effects of surface condition on drawbar pull and slip can be seen. The lowest drawbar pulls were developed in tests with treaded tires at 15% deflection on flooded surfaces; no drawbar pull was developed until wheel slip was above 40%. In one test with treaded tires at 15% deflection and two tests with smooth tires (one at 15% and one at 35% deflection) the vehicle was immobilized on the flooded surface before drawbar pull could be developed (table 2).

45. Bottomland area, natural surface. Six tests were conducted on natural, soft soil conditions and two tests were conducted on firm soil (plate 9). Twenty-five percent of the firm soil surface was covered with

2- to 3-in.-high grass. The soft soil surfaces were bare for two tests and had a 10% cover of 2- to 3-in.-high grass for the remaining four tests. Effects of the grass cover on drawbar pull in this area could not be determined; effects of soft soil (CI_0* range 11-43) on the drawbar pull-slip curve can be seen when compared with curves for tests on firm soil (CI_0 range 102-111).

Hicks' farm

46. Natural surface. Four tests were conducted on natural 35% grass-covered surfaces. Two tests (AC-52 and AC-53) were conducted on dry surfaces and two tests (AC-54 and AC-55) were conducted on the same surfaces after sprinkling with 0.25 in. of water. The effect of sprinkling can be seen by comparing drawbar pull-slip curves for similar tire deflections in plate 10.

47. Prepared surface. After completion of tests on the natural surface, the grass and contaminated soil surfaces were removed by a motor grader. Fifteen tests were conducted on dry and sprinkled surfaces with treaded and smooth tires at 15% and 35% deflections, plates 11 and 12. For a given tread pattern and tire deflection, pulls on dry surfaces were generally about the same for each test; for tests after surfaces were sprinkled (plate 12), some variations in pull occurred, probably because of differences in amounts of water applied or differences in elapsed time between sprinkling and running the test.

Sunflower canal road

48. Fourteen tests were conducted on the Sunflower canal road (plate 13). One test (test R-5) was conducted on a dry surface to establish a base line. The other tests were conducted to determine the effects of amount of water application and elapsed time between wetting and conduct of the test on drawbar pull and slip. Tests were conducted with treaded tires at 15% deflection. Examination of moisture contents (table 1) and drawbar pull-slip curves (plate 13) indicates that surface wetting from rainfall had less effect on reducing drawbar pull than artificial wetting.

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* CI_0 designates cone index at the surface, i.e. 0-in. depth.

Mississippi River sand beach

49. Twelve tests were conducted on the Mississippi River beach (plate 14). Tests were conducted on dry, moist, and wet sand with both treaded and smooth tires at 15% and 35% deflections. Moist and wet sands permitted higher opt TC than dry sand for both tire patterns and both deflections. Higher opt TC's were developed for smooth tires than for treaded tires for each sand condition and tire deflection, except dry sand at 15% deflection. This test (test AS-37) with smooth tires shows that the vehicle was experiencing about 50% wheel slip before developing any traction; this test may be in error.

Opt TC for Treaded Tires at 15% Deflection and Soil Property Measurements

50. In the previous paragraphs, average drawbar pull-slip curves were discussed and data points and average curves were shown in plates 1-14. Also shown in the plates were optimum tractive coefficient (opt TC) values for each curve as determined by the method given in paragraph 38. In this part of the analysis the relations between opt TC and soil property measurements will be presented. These relations will be determined first on the basis of test results of the 50 tests with treaded tires at 15% deflection. For those soil property measurements that show some degree of correlation with opt TC, results of the remaining tests (32 with treaded tires at 35% deflection, and 12 tests each with smooth tires at 15% and 35% deflections) will be used to complete the analysis.

Opt TC versus CI

51. Preliminary analysis of data indicated that relations between opt TC (table 2 and plates 1-14) and CI (table 3) at all depths were poor; however, the surface CI (CI_0) value appeared to have a better relation with opt TC than CI at other depths and is, therefore, shown in plate 15 for each test area and in plate 16 for all tests. CI data measured with the recording penetrometer were used when available. During a few tests on WES upland and bottomland areas and at Hicks' farm this device was inoperative; therefore, data measured with the standard penetrometer were used. CI_0 values above 300 were plotted on the 300+ line since it was felt that soils

with surface strengths between 300 CI and maximum capacity of the instrument (750 CI) would have undetectable effects on opt TC. It can be seen, particularly in plate 15, that effects of wet surface layers on opt TC are not measurable by the cone penetrometer. For example in fig. a, test B-16 was conducted on a sprinkled surface with an extremely high CI_0 but an opt TC of only 0.19 was developed, while in test 28 on a dry surface and CI_0 of 287 an opt TC of 0.80 was developed. Lack of correlation between opt TC and CI_0 can also be seen in fig. d, which records data from Sunflower canal road where nine tests were conducted on soil with CI_0 greater than 300 and opt TC ranged from 0.59 (test R-5, dry surface) to 0.17 (test R-1, sprinkled surface).

Opt TC versus multiprobe index (MPI)

52. Preliminary analysis of data indicated that relations between opt TC (table 2 and plates 1-14) and MPI (table 3) were best for MPI at the 1/4-in. depth ($MPI_{1/4}$) as shown in plate 17 for individual test areas and in plate 18 for all tests with treaded tires at 15% deflection. MPI data were not collected for all tests because of electrical-mechanical problems with the equipment. Examination of plates 17 and 18 indicates that multiprobe measurements correlate better with opt TC than cone penetrometer measurements (plates 15 and 16) discussed in the previous paragraph. There is, however, still considerable scatter in the data in plate 17.

Opt TC versus shear stress (S) measurements with sheargraph

53. Relations between opt TC and shear stress as measured with the sheargraph metal vaned head (S_v) and the rubber head (S_r) are discussed below.

54. S_v. Opt TC versus S_v is shown in plates 19 and 20 for treaded tires at 15% deflection. On firm, dry surfaces, particularly prepared surfaces, the vaned shear head produced maximum shear stresses that exceeded instrument capability; therefore, for about 26 tests S_v was not determined. A general trend of increasing opt TC with increasing S_v exists for tests in the stress building (fig. a, plate 19) and WES upland and bottomland tests (fig. b, plate 19).

55. S_r. Opt TC versus S_r is shown in plates 21 and 22 for treaded

tires at 15% deflection. S_r gave the best correlation with opt TC of all measurements examined. For individual test areas (plate 21) correlations were good, but after tests were grouped (plate 22) some scatter was apparent. Some scatter may be attributed to differences in surface cover (grass or bare) or differences in soil types (CH, ML, and SP). Also for tests A-2, -4, and -5 (fig. b, plate 21) a thin surface crust was not removed before S_r measurements were made; therefore, S_r values are higher than they should be for the corresponding opt TC value. However, the low opt TC values for these tests were caused by the low mass soil strength below the thin surface crust as indicated by the low (less than 50) CI_0 values, plate 15.

Opt TC versus shear stress (S) as measured by soil truss

56. Relations between opt TC and shear stress as measured with the soil truss rubber ski (S_s) and center-load tare device (S_t) are discussed below. Data are shown in plates 23-26.

57. S_s. Data were measured for 47 of the 50 tests with treaded tires at 15% deflection. The three tests for which S_s data were not measured were soft surface soils in which shear occurred without normal load, indicating the instrument itself was too heavy for these particular conditions. Predicting opt TC from S_s shows some promise as indicated for WES areas and Hicks' farm; however, correlations are not considered as good as shear stress measured with the sheargraph (S_r).

58. S_t. The strength of the soil at Hicks' farm was beyond the capacity of the center-load tare measuring device (and it was believed that that on the Sunflower canal road would prove to be also). It was concluded, therefore, that this instrument was not suitable for measurements of surface layers except perhaps for sand surface layers for which the instrument was originally designed.

Opt TC versus traction index (TI)

59. Plots of opt TC versus TI are shown in plates 27 and 28 for treaded tires at 15% deflection. Very little data were collected with the friction wheel because of the difficulty of moving it from one test area to

another. The two plates indicate that correlations of opt TC and TI are not good.

Summary of relations between
opt TC and soil property measurements

60. Data were insufficient to determine, quantitatively, the effects of surface cover, soil type, surface treatments (sprinkled, flooded, etc.), or prepared versus natural surfaces on opt TC. Obviously, however, different surface conditions did affect opt TC values in that dry, firm surfaces yielded the highest opt TC values, but when these surfaces were sprinkled, flooded, or covered with mud, opt TC values were reduced considerably. For the most part, the reductions in opt TC values are reflections of reductions in surface strengths as measured principally with the multiprobe penetrometer and the sheargraph. From the preceding analysis based on the tests with treaded tires at 15% deflection, $MPI_{1/4}$ and S_r best correlate with opt TC.

Effects of Tire Characteristics, $MPI_{1/4}$, and S_r on Opt TC

61. In the previous paragraphs, relations between opt TC and soil property measurements for treaded tires at 15% tire deflection were analyzed since it was under these conditions that most tests were conducted. From the analysis, it appeared that $MPI_{1/4}$ and S_r were the measurements that would best correlate with opt TC. In the following paragraphs, the effects of tire characteristics (tread pattern and deflection) on opt TC are discussed. In discussions concerning $MPI_{1/4}$ and S_r it will be necessary to refer to the preceding analysis and to previously referenced plates showing treaded tires at 15% deflection.

Opt TC versus $MPI_{1/4}$ for treaded tires

62. Relations between opt TC and $MPI_{1/4}$ for treaded tires at 15% deflection are shown in plate 18. A curve of best visual fit has been drawn through the data points. To obtain a measure of the scatter of data around the curve, a count was made of the tests that plotted inside and outside an arbitrary ± 0.10 opt TC deviation from the curve. Of the total of 39 tests, 28 tests (72%) were within ± 0.10 opt TC deviation. The

average deviation of opt TC for the 11 tests (28%) outside the ± 0.10 deviation limit was 0.28. The greatest deviations were for one test (S-28) on a prepared dry surface and two tests (B-16 and AC-43) on prepared sprinkled surfaces. Average deviation of opt TC from the curve for the 39 tests was 0.11.

63. Relations between opt TC and $MPI_{1/4}$ for treaded tires at 35% deflection are shown in plate 29. The data points in this plate were similarly analyzed. Of the total of 26 tests, 16 tests (62%) were within a deviation of ± 0.10 opt TC of the average curve. Average deviation of opt TC for the 10 tests (38%) outside the ± 0.10 deviation limit was 0.27. As for 15% deflection, the greatest deviations were for tests on prepared dry surfaces (S-3, -4, and -29) and tests on prepared sprinkled surfaces (B-17 and AC-44). Average deviation of opt TC from the curve for the 26 tests was 0.11.

Opt TC versus $MPI_{1/4}$ for smooth tires

64. Relations between opt TC and $MPI_{1/4}$ for smooth tires at 15% and 35% deflections are shown in plates 30 and 31, respectively. Eleven tests were conducted at each deflection and, as can be seen in the two plates, correlations were poor; therefore, average curves were not drawn.

Opt TC versus S_r for treaded tires

65. Relations between opt TC and S_r for treaded tires at 15% deflection are shown in plate 22. A curve of best visual fit was drawn through the data points. To obtain a measure of scatter of data points about the curve, an analysis was performed similar to the one described for opt TC versus $MPI_{1/4}$ for treaded tires at 15% deflection (paragraph 62). Of the total of 49 tests, 28 tests (57%) plotted within a ± 0.10 opt TC deviation of the average. Average opt TC deviation of 18 tests (excluding tests A-2, A-4, and A-5 for reasons described in paragraph 55) above ± 0.10 was 0.17. The greatest deviation was for test S-28 (prepared dry surface). Average deviation of opt TC from the curve for the 49 tests was 0.11.

66. Relations between opt TC and S_r for treaded tires at 35% deflection are shown in plate 32. A total of 31 tests were conducted; 24 tests

(77%) plotted within a ±0.10 opt TC deviation of the average. The greatest deviation (0.41) occurred for test A-3, natural soil with a slightly crusted surface underlain by soft soil. Average deviation of opt TC from the curve for the 31 tests was 0.09.

Opt TC versus S_r for smooth tires

67. Relations between opt TC and S_r for smooth tires at 15% and 35% deflections are shown in plates 33 and 34, respectively. Eleven tests were conducted at each deflection, and curves of best visual fit were drawn through the data points. For 15% deflection, 55% of the tests plotted within ±0.10 opt TC deviation of the average. For 35% deflection, 73% of the tests plotted within ±0.10 opt TC deviation of the average. Average deviation of opt TC from the curve for the 11 tests at 15% deflection was 0.11 and for the 11 tests at 35% deflection was 0.08.

Summary of opt TC versus $MPI_{1/4}$ and S_r for treaded and smooth tires

68. Relations of opt TC and $MPI_{1/4}$ and S_r for treaded and smooth tires are summarized in the following tabulation:

Soil Strength Measurement and Tire Characteristic	Plate No.	Total No. of Data Points	% of Data Points Within ±0.10 Opt TC Dev of Avg Curve	Avg Dev of All Data Points from Avg Curve
$MPI_{1/4}$; treaded, 15% defl	18	39	72	0.11
$MPI_{1/4}$; treaded, 35% defl	29	26	62	0.11
	Total	65	Avg 67	Avg 0.11
S_r; treaded, 15% defl	22	49	57	0.11
S_r; treaded, 35% defl	32	31	81	0.09
	Total	80	Avg 69	Avg 0.10
S_r; smooth, 15% defl	33	11	55	0.11
S_r; smooth, 35% defl	34	11	73	0.08
	Total	22	Avg 64	Avg 0.10

From the tabulation above, it can be seen that $MPI_{1/4}$ and S_r showed some promise for predicting opt TC; however, S_r was probably the better of the two. Had sufficient tests been conducted on a wide range of surface

conditions, it is conceivable that the relations could be improved for both measurements by accounting for differences in soil type, surface cover, and, possibly, other factors instead of combining all data for a given tread pattern and tire deflection as was necessary herein.

Tentative equations
for predicting opt TC

69. The curves of best visual fit for each tread pattern and deflection (see plate numbers in paragraph 68) are summarized in plate 35. Analysis of these curves resulted in the development of tentative equations for predicting opt TC based on deflection (expressed as a decimal), $MPI_{1/4}$, and S_r.

70. Treaded tires. The two deflection curves shown in figs. a and b of plate 35 for opt TC versus $MPI_{1/4}$ and opt TC versus S_r, respectively, may be collapsed on the basis of deflection as follows:

$$\text{opt TC} = 0.04 \times \text{deflection}^{0.195} \times MPI_{1/4}^{0.545}$$

$$\text{opt TC} = 0.265 \left[(\text{deflection} \times S_r)^{0.815}\right]$$

71. Smooth tires. The two deflection curves shown in fig. c of plate 35 for opt TC versus S_r may be collapsed on the basis of deflection as follows:

$$\text{opt TC} = 0.265 \left[(\text{deflection} \times S_r) - 0.47\right]^{0.815}$$

Curves were not developed for opt TC versus $MPI_{1/4}$ for smooth tires.

72. Comparison of measured and predicted opt TC. Comparisons were made of measured opt TC values as shown in table 2 and predicted opt TC values from equations shown in the preceding paragraph. The comparisons are shown graphically in plate 36 and are summarized in the tabulation on the following page.

Soil Strength Measurement and Tire Tread Pattern	Total No. of Data Points	% of Data Points Within ±0.10 Opt TC of the 1:1 Line	Avg Dev of Predicted from Measured Opt TC
$MPI_{1/4}$, treaded	65	63	0.15
S_r, treaded	80	60	0.11
S_r, smooth	22	63	0.09
	Average	62	0.12

73. When comparing the above-listed percentages with percentages of points within ±0.10 opt TC of average curves for each deflection in paragraph 68, it can be seen that by collapsing the curves on the basis of deflection some reduction (approximately 4 percentage points) is effected in the number of points within ±0.10 opt TC of the average lines. The overall average deviation of predicted from measured values was 0.12, slightly higher than that for the individual curve for each deflection in paragraph 68.

Effects of tread pattern on opt TC

74. Effects of tread pattern on opt TC are shown in plate 37. In this plate opt TC for smooth tires was plotted versus opt TC for treaded tires for the same deflection and for the same test conditions. For example, item 10, table 1, describes the test conditions for test S-20 (smooth tires at 15% deflection) and test S-21 (treaded tires at 15% deflection); opt TC's for these two tests are plotted at 0.01 (test S-20, table 2) and 0.14 (test S-21, table 2), in fig. a, plate 37. Sixteen different test conditions (tests at two different deflections for the same test condition were considered as two different test conditions) were used in determining effects of tread pattern on opt TC.

75. Nine of the ten tests on prepared surfaces show opt TC for treaded tires to be higher than opt TC for smooth tires. For the four sand tests opt TC's for treaded tires were slightly higher than opt TC's for smooth tires for the two tests on dry sand, but opt TC's for smooth tires were higher than opt TC's for treaded tires for the two tests on wet sand. For both tests on pavement, treaded tires had slightly higher opt TC than smooth tires.

Effects of deflection on opt TC

76. Effects of deflection on opt TC are shown in plate 38. Of the 36 test conditions, tires at 35% deflection developed higher opt TC's than tires at 15% deflection, except for items 35, 38, and 40 for treaded tires and item 38 for smooth tires, all on dry conditions at Hicks' farm, and for pavement. However, these items (except for pavement) plot close to the 1:1 line. The reason for tires at 15% deflection developing higher opt TC's than tires at 35% deflection on pavement needs further investigation.

PART IV: SUMMARY OF TEST RESULTS AND RECOMMENDATIONS

Summary of Test Results

77. Results of the test program are summarized below:

  a. Data were insufficient to determine, quantitatively, the effects of surface cover, soil type, etc., on optimum tractive coefficient (opt TC). Qualitatively, however, different surface conditions did affect opt TC values in that dry, firm surfaces yielded the highest opt TC values, but when these surfaces were sprinkled, flooded, or covered with mud, opt TC values were reduced considerably. For the most part, the reductions in opt TC values were reflections of reductions in surface strengths (paragraph 60).

  b. The multiprobe penetrometer and the sheargraph show the most promise as instruments for measuring surface conditions for predicting surface traction (paragraph 60). However, other instruments should not be completely ruled out until other surface conditions and vehicles are tested.

  c. Tentative curves were developed for predicting opt TC based on tire deflection, tread pattern, and soil strength measurements with the multiprobe penetrometer and the sheargraph (paragraphs 69-71).

  d. Comparisons of measured and predicted opt TC's show average deviations as follows:

    Multiprobe index ($MPI_{1/4}$), treaded tires only = 0.15

    Sheargraph (S_r), treaded tires = 0.11

    Sheargraph (S_r), smooth tires = 0.09 (paragraph 72).

  e. In most tests for the same test conditions and deflections treaded tires developed higher pulls than smooth tires except for tests on sand (plate 37).

  f. For the same test conditions and tread patterns higher pulls were developed with tires at 35% deflection than at 15% deflection except for tests on pavement and a few tests on dry, bare surfaces (plate 38).

Recommendations

78. It is recommended that:

  a. Surface traction studies be continued with different wheeled and tracked vehicles.

b. Surface traction studies be expanded to include other prepared and natural surfaces (level and sloping).

c. Search be continued for an instrument to best quantify surface conditions.

d. Measurements with the sheargraph and multiprobe penetrometer be continued in surface traction studies; however, different configurations of sensing elements and test procedures should be investigated for possible improvement of measuring capabilities.

Table 1

Summary of Mass and Surface Soil Properties

Item No.	Test No.	Mass Soil Properties* Dry Density pcf	Moisture Content % Dry Wt	Atterberg Limits LL	PL	PI	USCS Type	Surface Soil Properties: Moisture Content, % Dry Wt 0- to 1/4-in. Layer	0- to 1-in. Layer	1- to 3-in. Layer	Test Condition**
											Asphalt Pavement
1	P-1, -2, -3, -4	--	--	--	--	--	--	--	--	--	Dry surface; same test lane for each test
											Stress Building (Prepared Surface)
2	S-1	93.2	27.2	63	28	35	CH	--	27.4	27.4	Dry surface compacted with steel roller and then bladed smooth
3	S-2, -3	91.6	27.6					26.9	26.2	27.6	Dry surface compacted with steel roller and then bladed smooth
4	S-4, -5	93.0	26.7					25.0	26.4	28.1	Dry surface compacted with steel roller and then bladed smooth
5	S-6, -7	93.2	25.2					36.4	29.4	26.4	Above-described surface flooded with 1.2 in. water for approx 26 hr
6	S-8, -9	--	27.4					29.8	26.9	25.3	Above-described surface after draining all free water from surface
7	S-10, -11	--	31.6					42.4	33.0	28.8	Above-described lane after removing contaminated surface and flooding with 1.8 in. water for 25 hr
8	S-12, -13	95.1	29.5					33.2	32.0	27.4	Above-described surface after draining all free water from surface
9	S-14, -15	--	28.8					87.4	87.4	87.4	Compacted surface overlain with approx 3.0 in. of viscous CH soil
10	S-20, -21, -22	--	23.6					67.4	64.3	38.8	Compacted surface overlain with approx 1.0 in. of viscous CH soil
11	S-23, -24, -25	--	22.4					54.8	46.8	22.4	Compacted surface overlain with approx 0.75 in. of viscous CH soil
12	S-26, -27, -28, -29	94.4	23.6					25.0	25.0	22.5	Dry surface compacted with steel roller and then bladed smooth
											Hangar 4 (Prepared Surface)
13	B-16, -17	-	21.8	61	24	37	CH	27.6	22.1	21.8	Surface compacted with steel roller, bladed smooth, and sprinkled with approx 0.04 in. of water
14	B-18, -19	--	23.6	61	24	37	CH	33.4	21.5	23.6	Surface compacted with steel roller, bladed smooth, and sprinkled with approx 0.04 in. of water
											Upland Flat (Natural Surface)
15	A-1	102.7	20.1	39	22	17	CL	--	21.4	20.1	Dry surface, approx 70% of 2- to 3-in.-high grass cover
16	A-6	105.0	20.9	32	19	13	CL	14.0	17.6	19.9	Dry surface, approx 30% of 2- to 4-in.-high grass cover
17	A-9, -10	--	--	30	28	2	ML	15.3	13.7	13.0	Dry surface, approx 100% of 2- to 14-in.-high grass cover
18	A-11	83.8	14.2	30	28	2	ML	30.9	35.5	18.4	Above-described surface after sprinkling with 0.4 in. of water
19	A-12	86.6	24.9	30	28	2	ML	25.5	28.7	14.2	Above-described surface after sprinkling with 0.4 in. of water
											Upland Flat (Prepared Surface)
20	A-15, -16	95.7	22.6	30	28	2	ML	21.0	20.7	20.6	Dry surface compacted with steel roller and bladed smooth
21	A-17, -18	94.2	21.6					19.0	18.9	19.4	Same lane as described above
22	A-19	--	18.4					30.9	15.4	15.2	Above-described surface after sprinkling with 0.33 in. of water
23	A-20	--	--					23.2	21.4	17.4	Above-described surface after sprinkling with 0.41 in. of water
24	A-21, -22	--	--					27.2	19.8	15.8	Above-described surface after sprinkling with 0.41 in. of water
25	A-23	--	21.3					38.6	22.2	19.0	Above-described surface after sprinkling with 0.41 in. of water
26	A-24, -25, -26, -27, -28	--	24.9					56.5	30.0	24.4	Above-described surface after flooding
											Bottomland Flat+ (Natural Surface)
27	A-2	88.8	27.4	37	27	10	ML	32.4	35.3	30.3	Soft soil; bare surface
28	A-3	85.1	30.8					33.1	37.6	32.8	Soft soil; bare surface
29	A-4	90.7	25.4					31.1	34.5	30.5	Soft soil; approx 10% of 2- to 3-in.-high grass cover
30	A-5	90.2	28.4					35.2	34.2	29.4	Soft soil; approx 10% of 2- to 3-in.-high grass cover
31	A-7, -8	87.6	29.0					24.8	27.4	25.6	Firm dry soil; approx 25% of 2- to 3-in.-high grass cover
32	A-13, -14	92.5	25.0					36.4	35.[illegible]	31.8	Soft soil; approx 10% of 2- to 3-in.-high grass cover

(Continued)

* Atterberg limits data for the 0- to 6-in. layer; moisture content and density data for 3- to 6-in. layer. Lower [illegible] assumed to have similar soil properties.
** See text for more details of surface preparations.
\+ Hydraulic fill area, considered to be natural surface since no preparation was made for these tests.

Table 1 (Concluded)

Item No.	Test No.	Mass Soil Properties: Dry Density pcf	Mass Soil Properties: Moisture Content % Dry Wt	Mass Soil Properties: Atterberg Limits LL	Mass Soil Properties: Atterberg Limits PL	Mass Soil Properties: Atterberg Limits PI	Mass Soil Properties: USCS Type	Surface Soil Properties: Moisture Content, % Dry Wt, 0- to 1/4-in. Layer	Surface Soil Properties: Moisture Content, % Dry Wt, 0- to 1-in. Layer	Surface Soil Properties: Moisture Content, % Dry Wt, 1- to 3-in. Layer	Surface Soil Properties: Test Condition
											Hicks' Farm (Natural Surface)
33	AC-52, -53	--	23.2	68	33	35	CH	6.4	12.2	18.8	Natural pastureland surface. Approx 35% of 0.5-in.-high grass cover
34	AC-54, -55	--	25.3	68	33	35	CH	49.4	38.6	22.8	Above-described surface sprinkled with 0.25 in. of water
											Hicks' Farm (Prepared Surface)
35	AC-41, -42	--	24.0	68	33	35	CH	8.9	--	21.0	Dry, bare surface; grass removed with motor grader
36	AC-43, -44	--	24.4					49.0	30.2	22.0	Above-described surface sprinkled with 0.25 in. of water
37	AC-45	--	24.4					24.0	30.2	22.0	Above-described surface after drying 2-1/2 hr, resprinkled with 0.14 in. of water
38	AC-46, -47, -48, -49	--	24.2					14.0	19.6	21.6	Dry, bare surface; above-described test lane after removal of contaminated surface
39	AC-50, -51	--	25.6					41.4	32.0	21.7	Above-described surface sprinkled with 0.20 in. of water
40	AC-56, -57	--	26.0					7.0	17.6	21.5	Dry, bare surface; grass removed with motor grader
41	AC-58, -59	--	27.2					44.3	23.7	23.6	Above-described surface sprinkled with 0.25 in. of water
											Sunflower Canal Road (Prepared Surface)
42	R-5	--	--	73	30	43	CH	3.6	7.1	--	Dry, firm surface; compacted by vehicle traffic
43	R-4	--	--					28.3	13.7	--	Same surface as that for test R-5 after sprinkling with 0.125 in. of water. Test was run 15 min after sprinkling
44	R-3	--	--					31.1	15.1	--	Same surface as that for test R-5 after sprinkling with 0.125 in. of water. Test was run 15 min after sprinkling
45	R-2	--	--					33.2	15.6	--	Same surface as that for test R-5 after sprinkling with 0.125 in. of water. Test was run 10 min after sprinkling
46	R-1	--	--					43.1	23.9	--	Same surface as that for test R-5 after sprinkling with 0.25 in. of water. Test was run 5 min after sprinkling
47	R-9	--	--					32.4	20.3	--	Same surface as that for test R-5 after sprinkling with 0.25 in. of water. Test was run 20 min after sprinkling
48	R-10	--	--					26.0	16.8	--	Same surface as that for test R-5 after sprinkling with 0.125 in. of water. Test was run 20 min after sprinkling
49	R-12	--	--					25.4	23.7	--	Same surface as that for test R-5 after sprinkling with <0.10 in. of water. Test was run 2 min after sprinkling
50	R-11	--	--					20.8	26.6	--	Same surface as that for test R-5 after sprinkling with 0.25 in. of water. Test was run 253 min after sprinkling
51	R-13	--	--					8.0	16.8	--	Surface moist from light rain
52	R-14	--	--					19.8	18.2	--	Above-described surface sprinkled with <0.10 in. of water. Test was run 2 min after sprinkling
53	R-6	--	--					26.9	24.2	--	Surface wet from recent rain
54	R-7	--	--					35.7	29.0	--	Above-described surface sprinkled with 0.125 in. of water. Test was run 30 min after sprinkling
55	R-8	--	--					33.8	26.3	--	Same surface as that for test R-6 after sprinkling with 0.25 in. of water. Test was run 30 min after sprinkling
											Mississippi River Sand Beach (Natural Surface)
56	AS-29, -30, -37, -38	93.2	2.1	--	--	NP	SP	0.1	--	2.1	Dry sand surface 100 yd from water's edge
57	AS-31, -32	94.6	6.6	--	--			0.2	--	6.6	Moist sand surface 5 yd from water's edge
58	AS-33, -34, -39, -40	100.2	20.3	--	--			15.0	--	20.3	Wet sand surface adjacent to water's edge
59	AS-35, -36	96.7	18.7	--	--			16.5	--	18.7	Wet sand surface adjacent to water's edge

Table 2

Summary of Vehicle Performance Data

Test No.	Item No. in Table 1	Plate and Fig. No.	Tire: Smooth or Treaded	Tire: % δ*	Tractive Coefficient (TC): Max at ≤50% S**	TC: At 20% S	TC: Max at Any S	TC: Optimum Coefficient	TC: Optimum % S	Torque Output Coefficient (TQ)†: At Max TC ≤50% S	TQ: At TC 20% S	TQ: At Max TC Any S	TQ: At Optimum TC	TQ: At Zero Pull	Rut Depth in.
Asphalt Pavement															
P-1	1	1-a	Treaded	15	0.91	0.90	0.91	0.87	14	1.02	0.85	1.02	0.97	0.02	0.0
P-2	1	1-a	Treaded	35	0.83	0.82	0.91	0.78	12	0.96	0.95	0.96	0.88	0.05	0.0
P-3	1	1-b	Smooth	15	0.89	0.87	0.90	0.85	16	0.95	0.94	0.96	0.87	0.02	0.0
P-4	1	1-b	Smooth	35	0.80	0.78	0.82	0.76	16	0.85	0.84	0.86	0.83	0.04	0.0
Stress Building (Prepared Surface)															
S-1	2	2-a	Treaded	15	0.78	0.68	0.95	0.66	18	0.85	0.74	1.03	0.72	0.03	--
S-2	3	2-a	Treaded	15	0.78	0.68	0.95	0.66	18	0.85	0.74	1.03	0.72	0.03	0.7
S-3	3	2-b	Treaded	35	0.87	0.80	0.91	0.80	20	0.96	0.89	1.10	0.89	0.04	0.3
S-4	4	2-b	Treaded	35	0.87	0.80	0.91	0.80	20	0.96	0.89	1.10	0.89	0.04	0.3
S-5	4	2-a	Treaded	15	0.78	0.68	0.95	0.66	18	0.85	0.74	1.03	0.72	0.03	0.6
S-6	5	3-a	Treaded	15	0.31	0.12	0.40	0.26	42	0.36	0.16	0.48	0.31	0.03	0.5
S-7	5	3-b	Treaded	35	0.38	0.31	0.41	0.32	22	0.43	0.35	0.47	0.37	0.05	0.2
S-8	6	4-a	Treaded	15	0.33	0.26	0.36	0.29	28	0.40	0.32	0.58	0.29	0.06	0.9
S-9	6	4-b	Treaded	35	0.48	0.43	0.52	0.46	24	0.56	0.50	0.70	0.53	0.05	0.6
S-10	7	3-a	Treaded	15	0.15	0.12	0.17	0.13	30	0.23	0.17	0.24	0.20	0.07	1.0
S-11	7	3-b	Treaded	35	0.22	0.19	0.22	0.21	26	0.29	0.26	0.29	0.28	0.04	1.0
S-12	8	4-a	Treaded	15	0.16	0.15	0.16	0.15	24	0.24	0.24	0.40	0.23	0.08	0.7
S-13	8	4-b	Treaded	35	0.22	0.21	0.25	0.21	20	0.29	0.27	0.52	0.28	0.04	0.7
S-14	9	5-a	Treaded	15	0.12	0.07	0.12	0.11	38	0.18	0.12	0.18	0.17	0.05	3.0
S-15	9	5-b	Treaded	35	0.15	0.10	0.15	0.15	34	0.20	0.15	0.21	0.20	0.05	3.3
S-20	10	5-c	Smooth	15	0.01	0.01	0.03	0.01	38	0.04	0.04	0.06	0.04	0.03	1.1
S-21	10	5-a	Treaded	15	0.17	0.08	0.22	0.14	34	0.20	0.12	0.26	0.17	0.03	1.1
S-22	10	5-b	Treaded	35	0.15	0.10	0.15	0.15	34	0.20	0.15	0.21	0.20	0.05	1.4
S-23	11	5-b	Treaded	35	0.15	0.10	0.15	0.15	34	0.20	0.15	0.21	0.20	0.05	0.6
S-24	11	5-a	Treaded	15	0.12	0.06	0.22	0.11	38	0.16	0.09	0.26	0.14	0.03	0.7
S-25	11	5-c	Smooth	35	0.07	0.03	0.10	0.05	38	0.12	0.07	0.15	0.09	0.04	0.8
S-26	12	2-c	Smooth	15	0.74	0.61	0.74	0.64	22	0.76	0.63	0.76	0.66	0.01	0.1
S-27	12	2-c	Treaded	35	0.83	0.77	0.83	0.75	16	0.91	0.84	0.91	0.81	0.02	0.0
S-28	12	2-a	Treaded	15	0.85	0.82	0.86	0.80	18	0.89	0.86	0.90	0.84	0.03	0.1
S-29	12	2-b	Treaded	35	0.87	0.80	0.91	0.80	20	0.96	0.89	1.10	0.89	0.04	--
Hangar 4 (Prepared Surface)															
B-16	13	6-a	Treaded	15	0.24	0.13	0.31	0.19	36	0.26	0.16	0.34	0.23	0.02	0.0
B-17	13	6-a	Treaded	35	0.31	0.16	0.35	0.28	40	0.35	0.19	0.38	0.31	0.03	0.0
B-18	14	6-b	Smooth	15	0.03	0.01	0.04	0.02	34	0.05	0.04	0.06	0.04	0.02	0.0
B-19	14	6-b	Smooth	35	0.08	0.01	0.10	0.07	36	0.11	0.06	0.14	0.09	0.04	0.0
Upland Flat (Natural Surface)															
A-1	15	7-a	Treaded	15	0.48	0.47	0.48	0.45	16	0.52	0.51	0.52	0.48	0.05	0.5
A-6	16	7-a	Treaded	15	0.65	0.61	0.66	0.61	20	0.72	0.68	0.75	0.68	0.05	0.4
A-9	17	7-a	Treaded	15	0.48	0.47	0.48	0.45	16	0.52	0.51	0.52	0.48	0.05	0.6
A-10	17	7-b	Treaded	35	0.69	0.65	0.69	0.65	20	0.80	0.72	0.82	0.72	0.04	0.6
A-11	18	7-a	Treaded	15	0.43	0.43	0.43	0.42	18	0.71	0.69	0.71	0.48	0.05	0.5
A-12	19	7-b	Treaded	35	0.66	0.63	0.66	0.61	18	0.50	0.50	0.50	0.68	0.05	0.5
Upland Flat (Prepared Surface)															
A-15	20	8-c	Smooth	15	0.69	0.66	0.71	0.62	14	0.73	0.70	0.75	0.66	0.04	0.1
A-16	20	8-a	Treaded	15	0.65	0.59	0.66	0.59	20	0.72	0.68	0.75	0.67	0.05	0.5
A-17	21	8-b	Treaded	35	0.73	0.65	0.75	0.65	20	0.80	0.72	0.82	0.72	0.04	0.5
A-18	21	8-d	Smooth	35	0.70	0.67	0.71	0.64	14	0.77	0.74	0.79	0.72	0.04	0.1
A-19	22	8-a	Treaded	15	0.36	0.35	0.47	0.33	14	0.42	0.40	0.54	0.39	0.04	0.4
A-20	23	8-b	Treaded	35	0.49	0.42	0.49	0.46	26	0.56	0.49	0.56	0.52	0.03	0.3
A-21	24	8-d	Smooth	35	0.37	0.37	0.37	0.36	14	0.44	0.44	0.44	0.43	0.02	0.3
A-22	24	8-c	Smooth	15	0.30	0.28	0.30	0.30	12	0.35	0.32	0.35	0.34	0.03	--
A-23	25	8-b	Treaded	35	0.30	0.30	0.40	0.29	18	0.38	0.36	0.48	0.36	0.04	0.4
A-24	26	--	Smooth	15	--	--	--	0.00	100††	--	--	--	--	--	4.1
A-25	26	--	Smooth	35	--	--	--	0.00	100††	--	--	--	--	--	2.8
A-26	26	8-b	Treaded	35	0.10	0.07	0.12	0.10	28	0.17	0.16	0.22	0.18	0.08	2.2
A-27	26	8-a	Treaded	15	0.06	0.00	0.12	0.08	58	0.18	0.11	0.24	0.19	0.11	2.9
A-28	26	--	Treaded	15	--	--	--	0.00	100††	--	--	--	--	--	4.2
Bottomland Flat (Natural Surface)															
A-2	27	9-a	Treaded	15	0.11	0.03	0.31	0.10	42	0.24	0.20	0.45	0.24	0.14	2.2
A-3	28	9-b	Treaded	35	0.21	0.17	0.25	0.19	24	0.33	0.30	0.40	0.31	0.12	1.9
A-4	29	9-a	Treaded	15	0.11	0.09	0.32	0.08	16	0.22	0.20	0.41	0.20	0.12	1.9
A-5	30	9-a	Treaded	15	0.14	0.01	0.32	0.14	50	0.29	0.20	0.42	0.30	0.19	2.1
A-7	31	9-b	Treaded	35	0.75	0.66	0.77	0.69	24	0.80	0.72	0.82	0.77	0.04	0.6
A-8	31	9-a	Treaded	15	0.57	0.51	0.57	0.52	22	0.65	0.60	0.65	0.61	0.06	0.6
A-13	32	9-a	Treaded	15	0.03	--	0.17	0.03	46	0.21	0.19	0.32	0.21	0.19	3.9
A-14	32	9-b	Treaded	35	0.11	0.00	0.25	0.12	52	0.24	0.16	0.35	0.24	0.16	2.4

(Continued)

* δ = tire deflection.
** S = percent slip.
† TQ = torque output (lb) ÷ vehicle weight (lb).
†† Immobilization occurred before drawbar pulls could be developed.

Table 2 (Concluded)

Test No.	Item No. in Table 1	Plate and Fig. No.	Tire: Smooth or Treaded	Tire: % δ	Tractive Coefficient (TC): Max at ≤50% S	TC: At 20% S	TC: Max at Any S	TC: Optimum Coefficient	TC: Optimum % S	Torque Output Coefficient (TQ): At Max TC ≤50% S	TQ: At TC 20% S	TQ: At Max TC Any S	TQ: At Optimum TC	TQ: At Zero Pull	Rut Depth in.
Hicks' Farm (Natural Surface)															
AC-52	33	10-a	Treaded	15	0.60	0.53	0.60	0.55	22	0.65	0.58	0.65	0.60	0.04	0.1
AC-53	33	10-b	Treaded	35	0.72	0.65	0.72	0.65	20	0.72	0.66	0.73	0.70	0.04	0.2
AC-54	34	10-b	Treaded	35	0.26	0.24	0.26	0.25	22	0.30	0.28	0.30	0.29	0.02	0.5
AC-55	34	10-a	Treaded	15	0.14	0.10	0.18	0.12	32	0.19	0.15	0.23	0.17	0.05	0.7
Hicks' Farm (Prepared Surface)															
AC-41	35	11-a	Treaded	15	0.73	0.67	0.73	0.66	18	0.78	0.72	0.78	0.71	0.03	0.2
AC-42	35	11-b	Treaded	35	0.72	0.65	0.76	0.65	20	0.72	0.66	0.73	0.70	0.04	0.1
AC-43	36	12-a	Treaded	15	0.14	0.10	0.18	0.12	32	0.19	0.15	0.23	0.17	0.05	0.3
AC-44	36	12-b	Treaded	35	0.20	0.17	0.20	0.18	22	0.24	0.21	0.24	0.22	0.05	0.2
AC-45	37	11-b	Treaded	35	0.69	0.65	0.69	0.65	20	0.72	0.66	0.73	0.70	0.04	0.1
AC-46	38	11-a	Treaded	15	0.73	0.67	0.73	0.66	18	0.78	0.72	0.78	0.71	0.03	0.1
AC-47	38	11-b	Treaded	35	0.72	0.65	0.76	0.65	20	0.72	0.66	0.73	0.70	0.04	0.0
AC-48	38	11-c	Smooth	35	0.65	0.60	0.69	0.58	16	0.71	0.65	0.75	0.63	0.03	0.0
AC-49	38	11-c	Smooth	15	0.70	0.64	0.72	0.64	20	0.71	0.66	0.72	0.66	0.03	0.1
AC-50	39	12-c	Smooth	15	0.06	0.04	0.10	0.05	28	0.08	0.06	0.12	0.07	0.02	0.2
AC-51	39	12-c	Smooth	35	0.15	0.13	0.25	0.14	24	0.20	0.18	0.31	0.19	0.04	0.1
AC-56	40	11-a	Treaded	15	0.73	0.67	0.73	0.66	18	0.78	0.72	0.78	0.71	0.03	0.0
AC-57	40	11-b	Treaded	35	0.72	0.65	0.76	0.65	20	0.72	0.66	0.73	0.70	0.04	0.0
AC-58	41	12-b	Treaded	35	0.16	0.14	0.16	0.15	22	0.21	0.20	0.21	0.20	0.05	0.1
AC-59	41	12-a	Treaded	15	0.10	0.08	0.13	0.10	32	0.19	0.15	0.23	0.17	0.05	0.2
Sunflower Canal Road (Prepared Surface)															
R-1	46	13-d	Treaded	15	0.19	0.17	0.25	0.17	23	--	--	--	--	--	--
R-2	45	13-c	Treaded	15	0.30	0.26	0.34	0.27	25	--	--	--	--	--	--
R-3	44	13-d	Treaded	15	0.26	0.23	0.30	0.23	20	--	--	--	--	--	--
R-4	43	13-c	Treaded	15	0.40	0.36	0.42	0.35	18	--	--	--	--	--	--
R-5	42	13-a	Treaded	15	0.66	0.60	0.74	0.59	18	--	--	--	--	--	--
R-6	53	13-b	Treaded	15	0.65	0.53	0.69	0.55	22	--	--	--	--	--	--
R-7	54	13-b	Treaded	15	0.21	0.15	0.28	0.17	30	--	--	--	--	--	--
R-8	55	13-b	Treaded	15	0.21	0.15	0.28	0.17	30	--	--	--	--	--	--
R-9	47	13-d	Treaded	15	0.26	0.23	0.30	0.23	20	--	--	--	--	--	--
R-10	48	13-c	Treaded	15	0.40	0.36	0.42	0.35	18	--	--	--	--	--	--
R-11	50	13-d	Treaded	15	0.52	0.34	0.65	0.46	36	--	--	--	--	--	--
R-12	49	13-c	Treaded	15	0.61	0.44	0.71	0.55	36	--	--	--	--	--	--
R-13	51	13-a	Treaded	15	0.63	0.55	0.71	0.55	20	--	--	--	--	--	--
R-14	52	13-a	Treaded	15	0.55	0.43	0.65	0.43	20	--	--	--	--	--	--
Mississippi River Sand Beach (Natural Surface)															
AS-29	56	14-a	Treaded	15	0.07	0.06	0.10	0.06	18	0.48	0.44	0.59	0.44	0.19	2.4
AS-30	56	14-b	Treaded	35	0.33	0.32	0.33	0.32	20	0.43	0.42	0.43	0.42	0.05	1.1
AS-31	57	14-a	Treaded	15	0.19	0.19	0.28	0.19	20	0.33	0.33	0.64	0.33	0.06	1.8
AS-32	57	14-b	Treaded	35	0.43	0.41	0.55	0.41	20	0.50	0.48	0.69	0.48	0.03	0.8
AS-33	58	14-b	Treaded	35	0.39	0.37	0.39	0.37	20	0.50	0.46	0.50	0.47	0.06	1.0
AS-34	58	14-a	Treaded	15	0.19	0.19	0.28	0.19	20	0.33	0.33	0.64	0.33	0.06	--
AS-35	59	14-c	Smooth	15	0.31	0.31	0.31	0.30	16	0.44	0.44	0.44	0.40	0.08	1.[illegible]
AS-36	59	14-d	Smooth	35	0.47	0.46	0.47	0.45	18	0.54	0.54	0.54	0.53	0.06	1.0
AS-37	56	14-c	Smooth	15	0.00	--	0.07	0.06	74	0.41	0.41	0.53	0.50	0.41	2.7
AS-38	56	14-d	Smooth	35	0.28	0.28	0.33	0.28	16	0.40	0.40	0.58	0.40	0.10	2.2
AS-39	58	14-d	Smooth	35	0.40	0.39	0.40	0.38	18	0.52	0.51	0.52	0.49	0.06	1.3
AS-40	58	14-c	Smooth	15	0.22	0.22	0.22	0.21	16	0.35	0.35	0.35	0.34	0.13	2.1

A

Table 3

Summary of Soil Strength Data

Test No.	Item No. in Table 1	Cone Index (CI) Standard Penetrometer							Recording Penetrometer							Multiprobe Index (MPI)							Met
		Depth Below Surface in Inches																					
		0	1	2	3	4	5	6	0	1	2	3	4	5	6	1/4	1/2	3/4	1	1-1/4	1-1/2	1-3/4	c_v
Asphalt Pavement																							
P-1	1	750+	--	--	--	--	--	--	750+	--	--	--	--	--	--	750+	--	--	--	--	--	--	--
P-2	1		--	--	--	--	--	--		--	--	--	--	--	--		--	--	--	--	--	--	--
P-3	1		--	--	--	--	--	--		--	--	--	--	--	--		--	--	--	--	--	--	--
P-4	1		--	--	--	--	--	--		--	--	--	--	--	--		--	--	--	--	--	--	--
Stress Building (Prepared Surface)																							
S-1	2	--	--	--	--	--	--	--	178	170	178	178	170	160	150	250+	293+	296+	300+	--	--	--	14.9
S-2	3	--	--	--	--	--	--	--	146	154	169	195	219+	250+	270+	160	158	156	155	152	153	157	15.5
S-3	3	--	--	--	--	--	--	--	146	154	169	195	219+	250+	270+	160	158	156	155	152	153	157	15.5
S-4	4	--	--	--	--	--	--	--	159	160	168	188	214+	234+	241+	159	164	163	161	162	161	163	16.5
S-5	4	--	--	--	--	--	--	--	159	160	168	188	214+	234+	241+	159	164	163	161	162	161	163	16.5
S-6	5	--	--	--	--	--	--	--	34	126	199	228	252	251	240	97	157	188	202	212	218+	224+	6.2
S-7	5	--	--	--	--	--	--	--	34	126	199	228	252	251	240	97	157	188	202	212	218+	224+	6.2
S-8	6	--	--	--	--	--	--	--	94	151	183	206	214	215	--	122	137	154	169	182	189	204	13.4
S-9	6	--	--	--	--	--	--	--	94	151	183	206	214	215	--	122	137	154	169	182	189	204	13.4
S-10	7	--	--	--	--	--	--	--	100	169	179	183	177	165	156	35	69	99	132	156	171	176	6.6
S-11	7	--	--	--	--	--	--	--	100	169	179	183	177	165	156	35	69	99	132	156	171	176	6.6
S-12	8	--	--	--	--	--	--	--	67	132	155	155	156	159	168	46	88	113	131	147	161	180	7.9
S-13	8	--	--	--	--	--	--	--	67	132	155	155	156	159	168	46	88	113	131	147	161	180	7.9
S-14	9	--	--	--	--	--	--	--	2	5	43	134	178	176	168	0	1	2	3	4	5	7	--
S-15	9	--	--	--	--	--	--	--	2	5	43	134	178	176	168	0	1	2	3	4	5	7	--
S-20	10	--	--	--	--	--	--	--	36	105	272	297	296	300+	--	0	0	19	68	68	68	68	--
S-21	10	--	--	--	--	--	--	--	36	105	272	297	296	300+	--	0	0	19	68	68	68	68	--
S-22	10	--	--	--	--	--	--	--	36	105	272	297	296	300+	--	0	0	19	68	68	68	68	--
S-23	11	--	--	--	--	--	--	--	97	276	300+	--	--	--	--	8	37	93	178	252	268	268	1.2
S-24	11	--	--	--	--	--	--	--	97	276	300+	--	--	--	--	8	37	93	178	252	268	268	1.2
S-25	11	--	--	--	--	--	--	--	97	276	300+	--	--	--	--	8	37	93	178	252	268	268	1.2
S-26	12	--	--	--	--	--	--	--	287+	300+	--	--	--	--	--	179+	300+	--	--	--	--	--	Beyond
S-27	12	--	--	--	--	--	--	--	287+	300+	--	--	--	--	--	179+	300+	--	--	--	--	--	of i
S-28	12	--	--	--	--	--	--	--	287+	300+	--	--	--	--	--	179+	300+	--	--	--	--	--	
S-29	12	--	--	--	--	--	--	--	287+	300+	--	--	--	--	--	179+	300+	--	--	--	--	--	
Hangar 4 (Prepared Surface)																							
B-16	13	--	--	--	--	--	--	--	426	416	438	448	484	510	544	300+	--	--	--	--	--	--	Beyond
B-17	13	--	--	--	--	--	--	--	426	416	438	448	484	510	544		--	--	--	--	--	--	of i
B-18	14	--	--	--	--	--	--	--	465	436	438	428	472	504	531		--	--	--	--	--	--	
B-19	14	--	--	--	--	--	--	--	465	436	438	428	472	504	531		--	--	--	--	--	--	
Upland Flat (Natural Surface)																							
A-1	15	66	143	225	266+	277+	263+	275+	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5.0
A-6	16	158	257+	294+	298+	300+	--	--	175	252+	296+	298+	300+	--	--	--	--	--	--	--	--	--	3.9
A-9	17	234	300+	--	--	--	--	--	286+	300+	--	--	--	--	--	214+	300+	--	--	--	--	--	4.5
A-10	17	249	296+	300+	--	--	--	--	287+	299+	300+	--	--	--	--	273+	300+	--	--	--	--	--	3.6
A-11	18	142	252+	290+	300+	--	--	--	188+	265+	298+	300+	--	--	--	200+	266+	276+	276+	292+	300+	--	3.9
A-12	19	128	268+	298+	300+	--	--	--	210+	288+	300+	--	--	--	--	220+	292+	300+	--	--	--	--	3.3
Upland Flat (Prepared Surface)																							
A-15	20	335	650+	704+	677+	640+	582+	552+	395	660+	696+	691+	666+	635+	608+	284	300+	--	--	--	--	--	3.0
A-16	20	335	650+	704+	--	--	--	--	395	660+	696+	691+	666+	635+	608+	284	300+	--	--	--	--	--	3.0
A-17	21	501	714	750+	--	--	--	--	417	722+	750+	--	--	--	--	294+	300+	--	--	--	--	--	3.7
A-18	21	501	714	750+	--	--	--	--	417	722+	750+	--	--	--	--	294+	300+	--	--	--	--	--	3.7
A-19	22	542	733+	750+	--	--	--	--	262	694+	750+	--	--	--	--	292+	300+	--	--	--	--	--	1.7
A-20	23	499	720+	750+	--	--	--	--	535	732+	750+	--	--	--	--	296+	300+	--	--	--	--	--	2.6
A-21	24	502+	738+	747	750+	--	--	--	544+	740+	746+	748+	750+	--	--	298+	300+	--	--	--	--	--	1.6
A-22	24	502+	738+	747	750+	--	--	--	544+	740+	746+	748+	750+	--	--	298+	300+	--	--	--	--	--	1.6
A-23	25	272	581+	728+	750+	--	--	--	190	584+	737+	750+	--	--	--	162+	222+	243+	266+	290+	299+	300+	1.2
A-24	26	--	--	--	--	--	--	--	36	198+	270+	267+	257+	250+	248+	2	4	32	51	93	130+	175+	0.7
A-25	26	--	--	--	--	--	--	--	36	198+	270+	267+	257+	250+	248+	2	4	32	51	93	130+	175+	0.7
A-26	26	--	--	--	--	--	--	--	49	173	213+	230+	208+	194+	190+	2	9	33	80	108	127+	155+	0.2
A-27	26	--	--	--	--	--	--	--	49	173	213+	230+	208+	194+	190+	2	9	33	80	108	127+	155+	0.2
A-28	26	--	--	--	--	--	--	--	15	27	40	75	105	133	125	--	--	--	--	--	--	--	--

(Continued)

* c = cohesion in psi, a = adhesion in psi, tan ∅ = tangent of angle of internal friction; S = shear stress in psi; subscript v denotes sheargraph me with rubber head.

** c, a, tan ∅, and S same as in preceding footnote for sheargraph; subscript s denotes soil truss measurements with rubber ski; subscript t denotes

Table 3

Summary of Soil Strength Data

...rometer ...ce in Inches 4	5	6	MPI 1/4	1/2	3/4	1	1-1/4	1-1/2	1-3/4	Cohron Sheargraph* Metal Vaned Head c_v	Tan ϕ_v	S_v	Rubber Head a_r	Tan ϕ_r	S_r	Soil Truss** Rubber Ski a_s	Tan ϕ_s	S_s	Center-Load Tare c_t	Tan ϕ_t	S_t	Traction Index (TI)
Asphalt Pavement																						
--	--	--	750+	--	--	--	--	--	--	--	--	--	0.4	0.721	23.4	0.0	0.810	25.8	--	--	--	--
--	--	--		--	--	--	--	--	--	--	--	--			12.6			13.8	--	--	--	--
--	--	--		--	--	--	--	--	--	--	--	--			30.0			33.3	--	--	--	--
--	--	--		--	--	--	--	--	--	--	--	--			12.7			13.8	--	--	--	--
Stress Building (Prepared Surface)																						
170	160	150	250+	293+	296+	300+	--	--	--	14.9	0.454	29.4	1.9	0.567	20.0	0.56	0.531	17.5	Beyond capability			--
219+	250+	270+	160	158	156	155	152	153	157	15.5	0.294	24.9	1.2	0.466	16.0	0.13	0.836	26.8	of instrument			29.7
219+	250+	270+	160	158	156	155	152	153	157	15.5	0.294	20.5	1.2	0.466	9.1	0.13	0.836	14.2				16.2
214+	234+	241+	159	164	163	161	162	161	163	16.5	0.402	23.3	1.3	0.588	11.2	0.18	0.782	13.4				7.8
214+	234+	241+	159	164	163	161	162	161	163	16.5	0.402	29.3	1.3	0.588	20.0	0.18	0.783	25.0				14.9
252	251	240	97	157	188	202	212	218+	224+	6.2	0.489	21.8	0.9	0.080	3.4	0.18	0.624	20.1	12.3	0.726	35.4	--
252	251	240	97	157	188	202	212	218+	224+	6.2	0.489	14.7	0.9	0.080	2.3	0.18	0.624	10.7	12.3	0.726	24.6	--
214	215	--	122	137	154	169	182	189	204	13.4	0.381	25.5	1.3	0.106	4.7	0.21	0.649	20.9	7.2	0.556	24.9	18.8
214	215	--	122	137	154	169	182	189	204	13.4	0.381	19.8	1.3	0.106	3.1	0.21	0.649	11.2	7.2	0.556	16.6	10.2
177	165	156	35	69	99	132	156	171	176	6.6	0.262	15.0	0.6	0.052	2.2	0.24	0.509	16.5	--	--	--	6.4
177	165	156	35	69	99	132	156	171	176	6.6	0.262	11.0	0.6	0.052	1.5	0.24	0.509	8.8	--	--	--	3.6
156	159	168	46	88	113	131	147	161	180	7.9	0.238	15.5	0.9	0.078	3.4	0.38	0.425	13.9	10.3	0.306	20.1	33.1
156	159	168	46	88	113	131	147	161	180	7.9	0.238	11.9	0.9	0.078	2.2	0.38	0.425	7.6	10.3	0.306	15.5	18.0
178	176	168	0	1	2	3	4	5	7	--	--	--	0.4	0.066	2.5	0.22	0.346	11.2	--	--	--	--
178	176	168	0	1	2	3	4	5	7	--	--	--	0.4	0.066	1.5	0.22	0.346	6.1	--	--	--	--
296	300+	--	0	0	19	68	68	68	68	--	--	--	0.07	0.072	3.0	0.12	0.326	13.5	--	--	--	7.8
296	300+	--	0	0	19	68	68	68	68	--	--	--	0.07	0.072	2.4	0.12	0.326	10.5	--	--	--	6.8
296	300+	--	0	0	19	68	68	68	68	--	--	--	0.07	0.072	1.3	0.12	0.326	5.6	--	--	--	5.0
--	--	--	8	37	93	178	252	268	268	1.2	0.078	2.5	1.2	0.046	2.0	0.12	0.363	6.3	--	--	--	6.4
--	--	--	8	37	93	178	252	268	268	1.2	0.078	3.7	1.2	0.046	2.7	0.12	0.363	11.7	--	--	--	7.2
--	-	--	8	37	93	178	252	268	268	1.2	0.078	2.5	1.2	0.046	2.0	0.12	0.363	6.3	--	--	--	6.4
--	--	--	179+	300+	--	--	--	--	--	Beyond capability			0.4	0.428	17.9	0.07	0.782	32.2	--	--	--	26.3
--	--	--	179+	300+	--	--	--	--	--	of instrument			0.4	0.428	7.7	0.07	0.782	13.4	--	--	--	12.1
--	--	--	179+	300+	--	--	--	--	--				0.4	0.428	14.1	0.07	0.782	25.0	--	--	--	20.9
--	--	--	179+	300+	--	--	--	--	--				0.4	0.428	7.6	0.07	0.782	13.3	--	--	--	12.0
Hangar 4 (Prepared Surface)																						
484	510	544	300+	--	--	--	--	--	--	Beyond capability			1.0	0.052	2.6	0.04	0.510	16.3	10.4	0.869	38.0	4.7
484	510	544		--	--	--	--	--	--	of instrument				0.052	1.9	0.04	0.510	8.6	10.4	0.869	25.2	2.5
472	504	531		--	--	--	--	--	--					0.070	3.9	Below capability			--	--	--	--
472	504	531		--	--	--	--	--	--					0.070	2.3	of instrument			--	--	--	--
Upland Flat (Natural Surface)																						
--	--	--	--	--	--	--	--	--	--	5.0	0.432	18.8	1.6	0.483	17.0	0.07	1.032	33.0	1.77	1.070	35.9	--
300+	--	--	--	--	--	--	--	--	--	3.9	0.596	22.9	0.0	0.733	23.4	0.03	0.836	26.7	1.96	0.898	30.6	--
--	--	--	214+	300+	--	--	--	--	--	4.5	0.652	25.3	0.7	0.577	19.1	0.12	0.811	26.0	2.85	0.672	24.3	--
--	--	--	273+	300+	--	--	--	--	--	3.6	0.769	16.6	0.9	0.521	9.7	0.11	0.774	13.2	2.85	0.672	14.2	--
--	--	--	200+	266+	276+	276+	292+	300+	--	3.9	0.630	24.0	0.7	0.464	15.5	0.16	0.659	21.2	1.85	1.033	34.8	--
--	--	--	220+	292+	300+	--	--	--	--	3.3	0.668	14.6	0.5	0.467	8.4	0.16	0.659	11.3	1.85	1.033	19.3	--
Upland Flat (Prepared Surface)																						
66+	635+	608+	284	300+	--	--	--	--	--	3.0	0.877	39.0	0.9	0.567	24.1	0.05	0.809	33.5	--	--	--	26.7
66+	635+	608+	284	300+	--	--	--	--	--	3.0	0.877	31.0	0.8	0.570	19.0	0.05	0.809	25.8	3.4	0.752	27.4	20.8
--	--	--	294+	300+	--	--	--	--	--	3.7	0.808	17.4	0.5	0.592	10.5	0.07	0.706	12.0	2.4	0.643	13.4	12.0
--	--	--	294+	300+	--	--	--	--	--	3.7	0.808	17.5	0.5	0.592	10.6	0.07	0.706	12.1	--	--	--	12.1
--	--	--	292+	300+	--	--	--	--	--	1.7	0.683	23.5	0.0	0.445	14.2	0.03	0.598	19.1	--	--	--	20.4
--	--	--	296+	300+	--	--	--	--	--	2.6	0.811	16.3	0.3	0.414	7.3	0.12	0.874	14.9	--	--	--	--
750+	--	--	298+	300+	--	--	--	--	--	1.6	0.822	15.6	0.6	0.456	8.4	0.12	0.724	12.5	--	--	--	14.4
750+	--	--	298+	300+	--	--	--	--	--	1.6	0.822	35.4	0.6	0.456	19.3	0.12	0.724	30.0	--	--	--	27.1
--	--	--	162+	222+	243+	266+	290+	299+	300+	1.2	0.532	10.2	0.0	0.414	7.0	0.03	0.602	10.2	--	--	--	10.0
257+	250+	248+	2	4	32	51	93	130+	175+	0.7	0.110	5.2	0.0	0.141	5.8	Below capability			--	--	--	--
257+	250+	248+	2	4	32	51	93	130+	175+	0.7	0.110	2.6	0.0	0.141	2.4	of instrument			--	--	--	7.3
208+	194+	190+	2	9	33	80	108	127+	155+	0.2	0.228	4.1	0.0	0.207	3.5				--	--	--	7.2
208+	194+	190+	2	9	33	80	108	127+	155+	0.2	0.228	7.5	0.0	0.207	6.6				--	--	--	12.9
105	133	125	--	--	--	--	--	--	--	--	--	--	0.0	0.156	5.0				--	--	--	--

(Continued)

...riction; S = shear stress in psi; subscript v denotes sheargraph measurements with metal vaned head; subscript r denotes sheargraph measurements

...denotes soil truss measurements with rubber ski; subscript t denotes soil truss measurements with center-load tare.

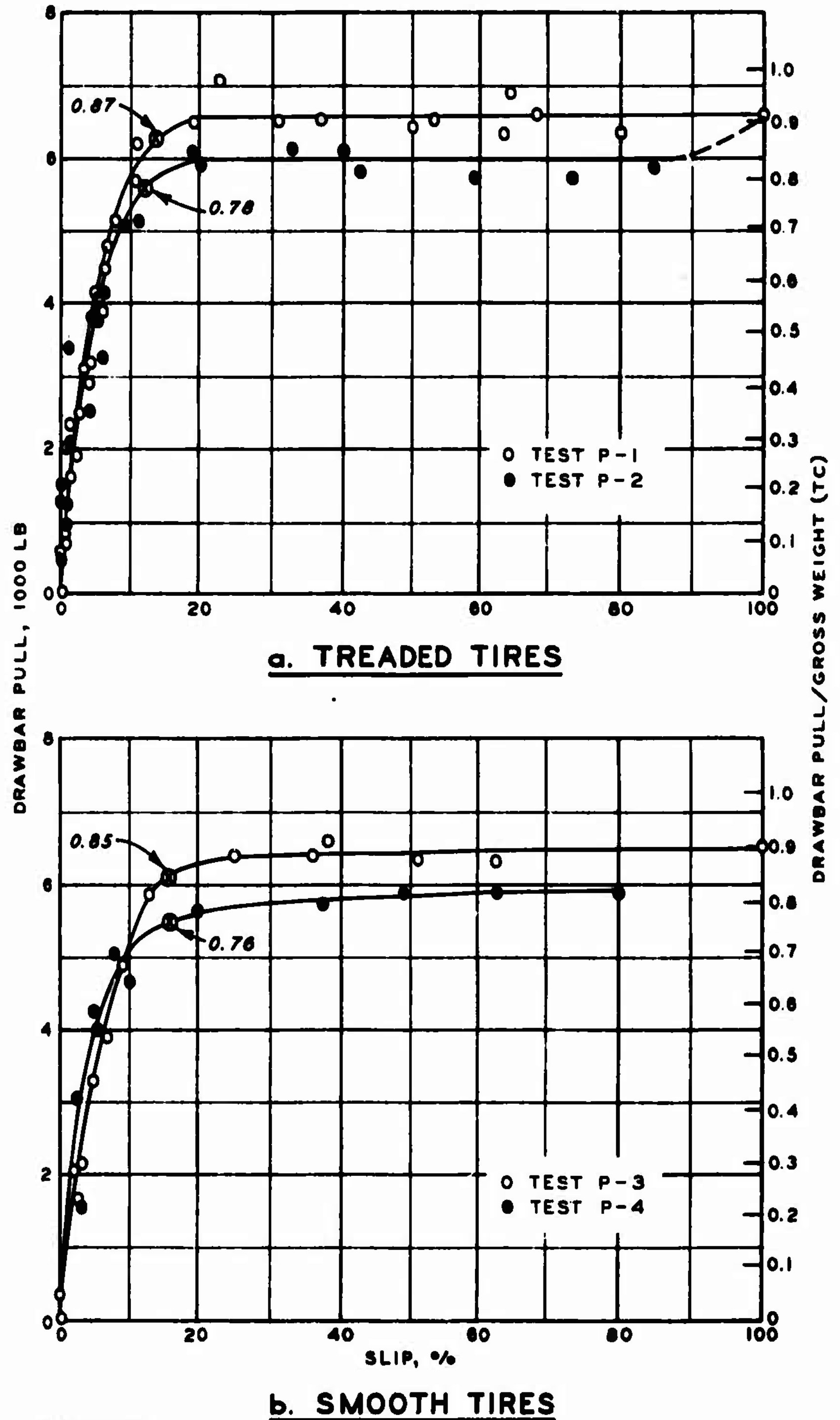
Table 3 (Concluded)

		Cone Index (CI)														Multiprobe Index (MPI)							Metal Vaned Head		Coh
		Standard Penetrometer							Recording Penetrometer																
		Depth Below Surface in Inches																							
Test No.	Item No. in Table 1	0	1	2	3	4	5	6	0	1	2	3	4	5	6	1/4	1/2	3/4	1	1-1/4	1-1/2	1-3/4	c_v	Tan ϕ_v	
																Bottomland Flat (Natural Surface)									
A-2	27	17	42	106	182+	198+	196+	188+	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.1	0.341	1
A-3	28	16	32	79	168	228+	240+	245+	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.6	0.248	
A-4	29	23	46	121	267+	300+	--	--	42	57	126	216	272	299+	300+	--	--	--	--	--	--	--	2.1	0.436	1
A-5	30	28	57	124	174	204	232	230	43	98	167	210	220	225	230	--	--	--	--	--	--	--	2.0	0.382	1
A-7	31	87	134	230	270+	288+	300+	--	102	172	299	276+	299+	300+	--	--	--	--	--	--	--	--	3.1	0.491	1
A-8	31	92	186	262+	291+	300+	--	--	111	224+	276+	248+	300+	--	--	--	--	--	--	--	--	--	2.5	0.523	1
A-13	32	8	18	36	70	157	245+	290+	11	35	66	122	215+	268+	288+	12	10	10	24	46	62	88	0.4	0.147	
A-14	32	8	26	68	126	204+	274+	286+	12	47	102	179+	258+	285+	290+	8	8	12	32	54	80	118	0.4	0.142	
																Hicks' Farm (Natural Surface)									
AC-52	33	293+	507+	550+	593+	621+	653+	661+	312+	454+	498+	500+	507+	532+	536+	233+	279+	292+	300+	--	--	--	Beyond capabili		
AC-53	33	293+	507+	550+	593+	621+	653+	661+	312+	454+	498+	500+	507+	532+	536+	233+	279+	292+	300+	--	--	--	of instrument		
AC-54	34	112	166	315	408+	455+	522+	565+	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
AC-55	34	112	166	315	408+	455+	522+	565+	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
																Hicks' Farm (Prepared Surface)									
AC-41	35	441	510+	526+	530+	525+	533+	544+	473+	509+	524+	525+	501+	509+	528+	300+	--	--	--	--	--	--	Beyond capabili		
AC-42	35	441	510+	526+	530+	525+	533+	544+	473+	509+	524+	525+	501+	509+	528+	300+	--	--	--	--	--	--	of instrument		
AC-43	36	174	526+	610+	655+	632+	628+	629+	234	595+	658+	628+	624+	599+	599+	300+	--	--	--	--	--	--	5.1	0.370	1
AC-44	36	174	526+	610+	655+	632+	628+	629+	234	595+	658+	628+	624+	599+	599+	300+	--	--	--	--	--	--	5.1	0.370	1
AC-45	37	306	526+	588+	588+	590+	598+	604+	302	552+	558+	586+	567+	570+	562+	252+	293+	299+	300+	--	--	--	Beyond capabili		
AC-46	38	698+	730+	728+	730+	734+	730+	734+	719+	720+	727+	734+	726+	726+	726+	300+	--	--	--	--	--	--	of instrument		
AC-47	38	698+	730+	728+	730+	734+	730+	734+	719+	720+	727+	734+	726+	726+	726+	300+	--	--	--	--	--	--			
AC-48	38	698+	730+	728+	730+	734+	730+	734+	719+	720+	727+	734+	726+	726+	726+	300+	--	--	--	--	--	--			
AC-49	38	698+	730+	728+	730+	734+	730+	734+	719+	720+	727+	734+	726+	726+	726+	300+	--	--	--	--	--	--			
AC-50	39	306+	701+	712+	707+	694+	698+	707+	294	648+	706+	692+	691+	688+	689+	121	246+	280+	290+	300+	--	--	5.1	0.423	2
AC-51	39	306+	701+	712+	707+	694+	698+	707+	294	648+	706+	692+	691+	688+	689+	121	246+	280+	290+	300+	--	--	5.1	0.423	1
AC-56	40	651+	652+	632+	614+	598+	586+	579+	--	--	--	--	--	--	--	--	--	--	--	--	--	--	Beyond capabili		
AC-57	40	651+	652+	632+	614+	598+	586+	579+	--	--	--	--	--	--	--	--	--	--	--	--	--	--	of instrument		
AC-58	41	281	506+	549	492+	417+	356+	318+	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
AC-59	41	281	506+	549	492+	417+	356+	318+	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
																Sunflower Canal Road (Prepared Surface)									
R-1	46	--	--	--	--	--	--	--	608+	750+	--	--	--	--	--	50	496	750+	--	--	--	--	--	--	
R-2	45	--	--	--	--	--	--	--	664+	750+	--	--	--	--	--	50	504	750+	--	--	--	--	--	--	
R-3	44	--	--	--	--	--	--	--	546+	750+	--	--	--	--	--	40	218	734+	750+	--	--	--	--	--	
R-4	43	--	--	--	--	--	--	--	712+	750+	--	--	--	--	--	139	517	750+	--	--	--	--	--	--	
R-5	42	--	--	--	--	--	--	--	750+	--	--	--	--	--	--	750+	--	--	--	--	--	--	--	--	
R-6	53	--	--	--	--	--	--	--	177	641+	750+	--	--	--	--	101	164	248	508	667	735	750+	--	--	
R-7	54	--	--	--	--	--	--	--	170	750+	--	--	--	--	--	67	309	710	750+	--	--	--	--	--	
R-8	55	--	--	--	--	--	--	--	294+	602+	715+	750+	--	--	--	158	723	750+	--	--	--	--	--	--	
R-9	47	--	--	--	--	--	--	--	628+	750+	--	--	--	--	--	171	750+	--	--	--	--	--	--	--	
R-10	48	--	--	--	--	--	--	--	308+	628+	750+	--	--	--	--	101	750+	--	--	--	--	--	--	--	
R-11	50	--	--	--	--	--	--	--	123	134	141	--	--	--	--	130	176	180	180	185	--	--	--	--	
R-12	49	--	--	--	--	--	--	--	206	156	156	--	--	--	--	252	439	384	320	253	--	--	--	--	
R-13	51	--	--	--	--	--	--	--	421	250	195	--	--	--	--	602+	717+	667+	539+	462	--	--	--	--	
R-14	52	--	--	--	--	---	--	--	466	324	209	--	--	--	--	603+	703+	695+	598	500	--	--	--	--	
																Mississippi River Sand Beach (Natural Surface)									
AS-29	56	28	49	94	146	190	236+	277+	37	51	85	136	180	222	263+	24	57	71	78	78	81	88	0.0	0.000	(
AS-30	56	28	49	94	146	190	236+	277+	37	51	85	136	180	222	263+	24	57	71	78	78	81	88			
AS-31	57	32	74	128	182	222	257+	284+	41	88	131	171	208	241+	271+	27	39	54	67	78	91	104			
AS-32	57	32	74	128	182	222	257+	284+	41	88	131	171	208	241+	271+	27	39	54	67	78	91	104			
AS-33	58	24	44	73	96	120	146	156	25	42	62	82	98	112	130	31	38	42	46	50	56	64			
AS-34	58	24	44	73	96	120	146	156	25	42	62	82	98	112	130	31	38	42	46	50	56	64			
AS-35	59	32	74	128	182	222	257+	284+	41	88	131	171	208	241+	271+	27	39	54	67	78	91	104			
AS-36	59	32	74	128	182	222	257+	284+	41	88	131	171	208	241+	271+	27	39	54	67	78	91	104			
AS-37	56	28	49	94	146	190	286+	277+	37	51	85	136	180	222	263+	24	57	71	78	78	81	88			
AS-38	56	28	49	94	146	190	286+	277+	37	51	85	136	180	222	263+	24	57	71	78	78	81	88			
AS-39	58	24	44	73	96	120	146	156	25	42	62	82	98	112	130	31	38	42	46	50	56	64			
AS-40	58	24	44	73	96	120	146	156	25	42	62	82	98	112	130	31	38	42	46	50	56	64			

13

Table 3 (Concluded)

…meter (…in Inches)			Multiprobe Index (MPI)							Cohron Sheargraph: Metal Vaned Head			Cohron Sheargraph: Rubber Head			Soil Truss: Rubber Ski			Soil Truss: Center-Load Tare			Traction Index (TI)
…	5	6	1/4	1/2	3/4	1	1-1/4	1-1/2	1-3/4	c_v	Tan ϕ_v	S_v	a_r	Tan ϕ_r	S_r	a_s	Tan ϕ_s	S_s	c_t	Tan ϕ_t	S_t	
Bottomland Flat (Natural Surface)																						
--	--	--	--	--	--	--	--	--	--	0.1	0.341	11.0	0.8	0.323	11.1	0.48	0.508	16.7	0.59	0.778	25.4	--
--	--	--	--	--	--	--	--	--	--	1.6	0.248	5.8	0.9	0.426	8.1	0.68	0.469	8.6	2.00	0.248	6.2	--
…2	299+	300+	--	--	--	--	--	--	--	2.1	0.436	16.0	0.8	0.580	19.3	0.60	0.577	19.0	0.75	0.600	19.9	--
…0	225	230	--	--	--	--	--	--	--	2.0	0.382	14.2	0.2	0.633	20.4	0.42	0.473	15.9	0.95	0.466	15.8	--
…9+	300+	--	--	--	--	--	--	--	--	3.1	0.491	11.4	0.0	0.723	12.2	0.08	0.812	13.8	1.52	0.756	14.3	--
…0+	--	--	--	--	--	--	--	--	--	2.5	0.523	19.3	0.0	0.724	23.1	0.09	0.671	21.5	1.12	0.808	26.9	--
…5+	268+	288+	12	10	10	24	46	62	88	0.4	0.147	5.1	0.7	0.210	7.4	0.35	0.487	15.9	--	--	--	--
…8+	285+	290+	8	8	12	32	54	80	118	0.4	0.142	2.8	0.8	0.207	4.3	0.35	0.488	8.6	--	--	--	--
Hicks' Farm (Natural Surface)																						
…7+	532+	536+	233+	279+	292+	300+	--	--	--	Beyond capability			0.9	0.426	14.5	0.13	0.648	20.8	Beyond capability			--
…7+	532+	536+	233+	279+	292+	300+	--	--	--	of instrument			0.9	0.426	8.1	0.13	0.648	11.2	of instrument			--
-	--	--	--	--	--	--	--	--	--				2.1	0.059	3.1	0.08	0.557	9.5				--
-	--	--	--	--	--	--	--	--	--				2.1	0.059	4.1	0.08	0.557	17.7				--
Hicks' Farm (Prepared Surface)																						
1+	509+	528+	300+	--	--	--	--	--	--	Beyond capability			0.1	0.433	13.9	0.06	0.634	20.3	Beyond capability			--
1+	509+	528+	300+	--	--	--	--	--	--	of instrument			0.1	0.433	7.5	0.06	0.634	10.9	of instrument			--
4+	599+	599+	300+	--	--	--	--	--	--	5.1	0.370	16.9	1.1	0.702	3.4	0.27	0.342	11.2				--
4+	599+	599+	300+	--	--	--	--	--	--	5.1	0.370	11.3	1.1	0.702	2.3	0.27	0.342	6.0				--
7+	570+	562+	252+	293+	299+	300+	--	--	--	Beyond capability			1.6	0.438	9.0	0.05	0.707	12.0				--
6+	726+	726+	300+	--	--	--	--	--	--	of instrument			0.2	0.490	15.8	0.02	0.675	21.5				--
6+	726+	726+	300+	--	--	--	--	--	--				0.2	0.490	8.5	0.02	0.675	11.5				--
6+	726+	726+	300+	--	--	--	--	--	--				0.2	0.490	8.6	0.02	0.675	11.6				--
6+	726+	726+	300+	--	--	--	--	--	--				0.2	0.490	20.3	0.02	0.675	27.7				--
1+	688+	689+	121	246+	280+	290+	300+	--	--	5.1	0.423	22.5	1.0	0.070	3.9	0.17	0.699	28.9				--
1+	688+	689+	121	246+	280+	290+	300+	--	--	5.1	0.423	12.0	1.0	0.070	2.2	0.17	0.699	12.1				--
-	--	--	--	--	--	--	--	--	--	Beyond capability			0.4	0.460	15.0	0.02	0.777	24.8				--
-	--	--	--	--	--	--	--	--	--	of instrument			0.4	0.460	8.2	0.02	0.777	13.1				--
-	--	--	--	--	--	--	--	--	--				0.5	0.094	2.1	0.08	0.492	8.4				--
-	--	--	--	--	--	--	--	--	--				0.5	0.094	3.5	0.08	0.492	15.8				--
Sunflower Canal Road (Prepared Surface)																						
-	--	--	50	496	750+	--	--	--	--	--	--	--	1.7	0.168	6.9	0.06	0.866	27.7	--	--	--	--
-	--	--	50	504	750+	--	--	--	--	--	--	--	3.0	0.216	9.9	0.03	0.883	28.2	--	--	--	--
-	--	--	40	218	734+	750+	--	--	--	--	--	--	2.0	0.144	6.6	0.13	0.698	22.4	--	--	--	--
-	--	--	139	517	750+	--	--	--	--	--	--	--	2.3	0.235	9.8	0.03	0.899	28.7	--	--	--	--
-	--	--	750+	--	--	--	--	--	--	--	--	--	0.9	0.461	15.6	0.00	0.623	19.9	--	--	--	--
-	--	--	101	164	248	508	667	735	750+	--	--	--	0.3	0.580	18.8	0.07	0.612	19.6	--	--	--	--
-	--	--	67	309	710	750+	--	--	--	--	--	--	1.9	0.185	7.8	0.13	0.836	26.8	--	--	--	--
-	--	--	158	723	750+	--	--	--	--	--	--	--	1.5	0.128	5.6	0.20	0.520	16.8	--	--	--	--
-	--	--	171	750+	--	--	--	--	--	--	--	--	2.3	0.157	7.3	0.02	0.930	29.7	--	--	--	--
-	--	--	101	750+	--	--	--	--	--	--	--	--	1.1	0.373	13.0	0.02	0.852	27.2	--	--	--	--
-	--	--	130	176	180	180	185	--	--	--	--	--	1.4	0.407	14.4	0.08	0.866	27.7	--	--	--	--
-	--	--	252	439	384	320	253	--	--	--	--	--	1.0	0.457	15.6	0.04	0.673	21.5	--	--	--	--
-	--	--	602+	717+	667+	539+	462	--	--	--	--	--	0.5	0.424	14.2	0.00	0.599	19.1	--	--	--	--
-	--	--	603+	703+	695+	598	500	--	--	--	--	--	0.8	0.394	13.5	0.00	0.711	22.7	--	---	--	--
Mississippi River Sand Beach (Natural Surface)																						
	222	263+	24	57	71	78	78	81	88	0.0	0.000	0.0	0.0	0.257	8.2	0.00	0.650	20.7	0.20	0.465	15.0	--
	222	263+	24	57	71	78	78	81	88					0.257	4.3		0.650	11.0	0.20	0.465	8.1	--
	241+	271+	27	39	54	67	78	91	104					0.330	10.5		0.625	19.9	0.42	0.719	23.4	--
	241+	271+	27	39	54	67	78	91	104					0.330	5.6		0.625	10.6	0.42	0.719	12.6	--
	112	130	31	38	42	46	50	56	64					0.320	5.4		0.675	11.4	0.20	0.531	9.2	--
	112	130	31	38	42	46	50	56	64					0.320	10.2		0.675	21.5	0.20	0.531	17.1	--
	241+	271+	27	39	54	67	78	91	104					0.356	14.6		0.650	26.7	0.42	0.625	26.1	--
	241+	271+	27	39	54	67	78	91	104					0.356	6.1		0.650	11.1	0.42	0.625	11.1	--
	222	263+	24	57	71	78	78	81	88					0.229	9.4		0.625	25.7	0.20	0.467	19.4	--
	222	263+	24	57	71	78	78	81	88					0.229	3.9		0.625	10.7	0.20	0.467	8.2	
	112	130	31	38	42	46	50	56	64					0.341	5.3		0.673	11.5	0.20	0.556	9.7	--
	112	130	31	38	42	46	50	56	64					0.341	14.0		0.673	27.7	0.20	0.556	23.0	--



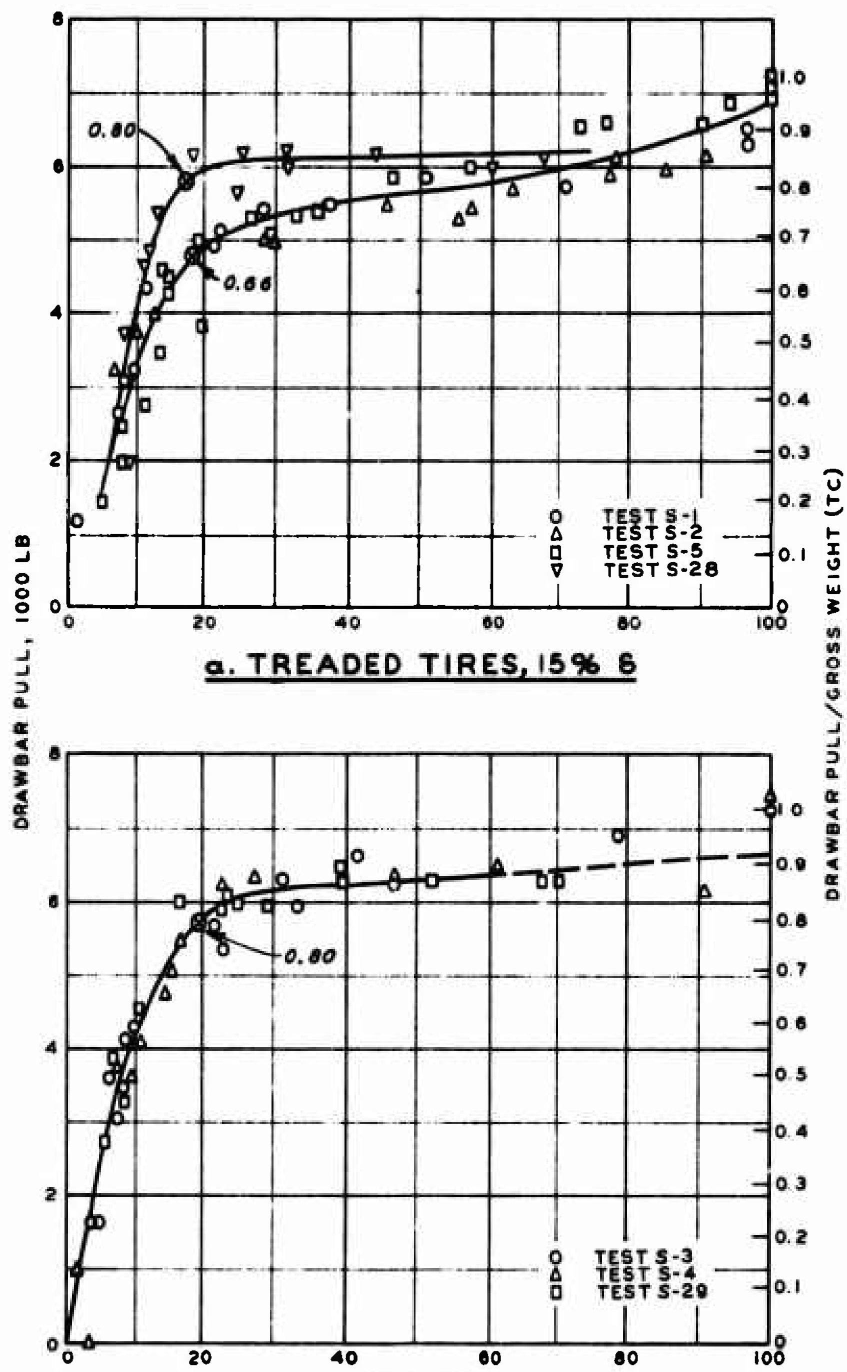
LEGEND

O 15 % DEFLECTION
● 35 % DEFLECTION

NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC

DRY ASPHALT PAVEMENT SURFACE

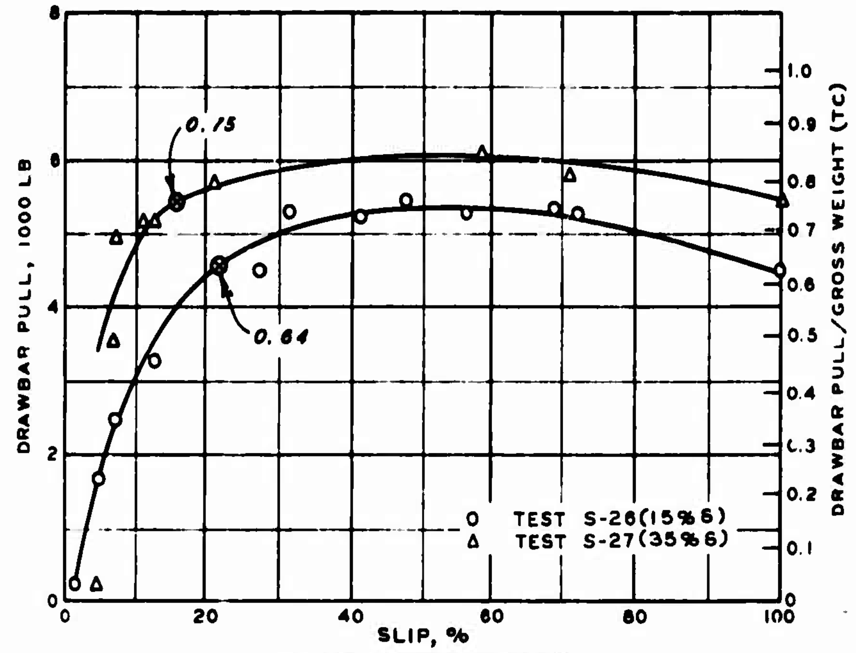


a. TREADED TIRES, 15% δ

b. TREADED TIRES, 35 % δ

NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC.
δ DESIGNATES DEFLECTION.

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC
STRESS BUILDING
PREPARED CH SOIL SURFACE
DRY

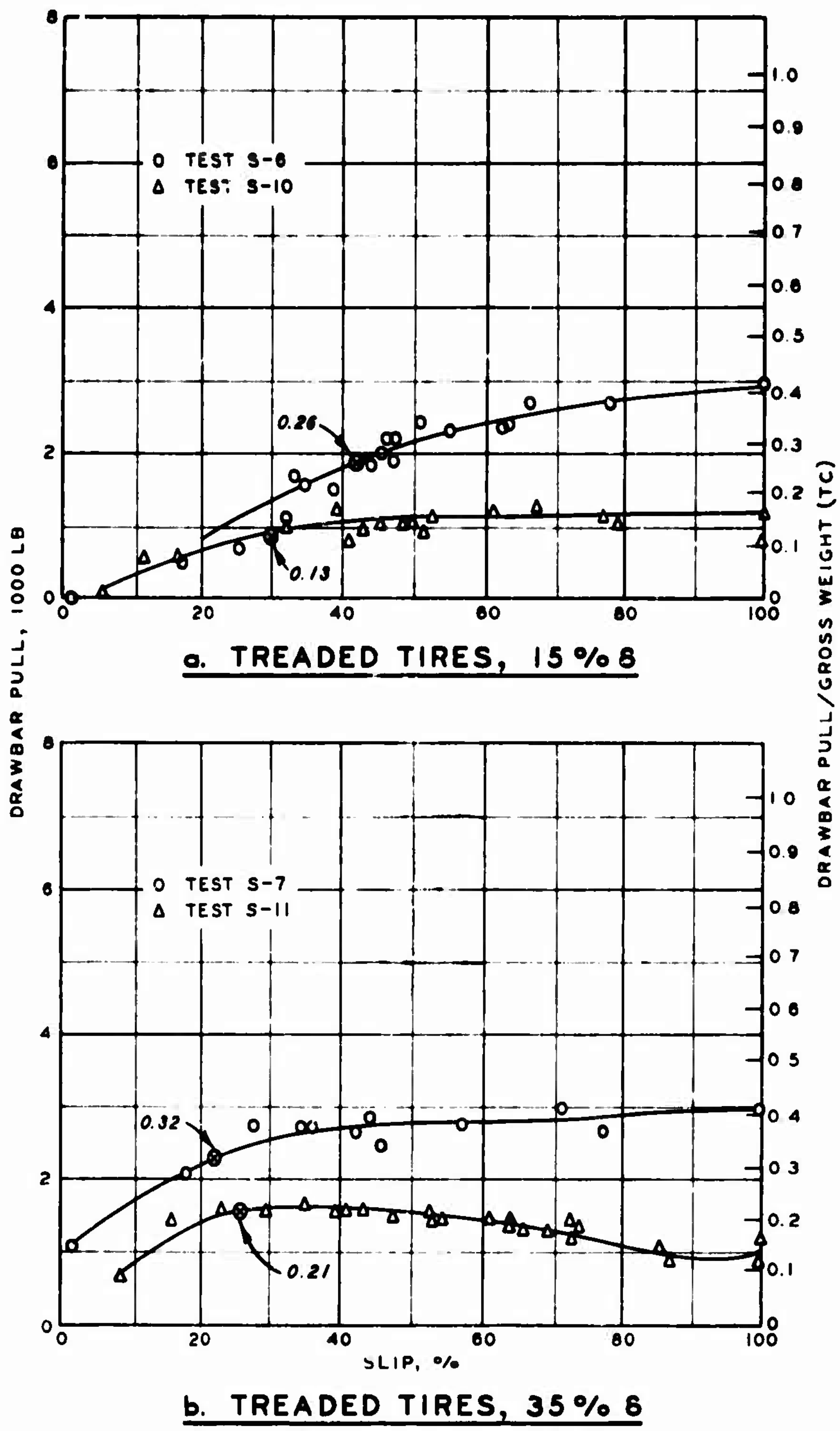


c. SMOOTH TIRES

NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC.
δ DESIGNATES DEFLECTION.

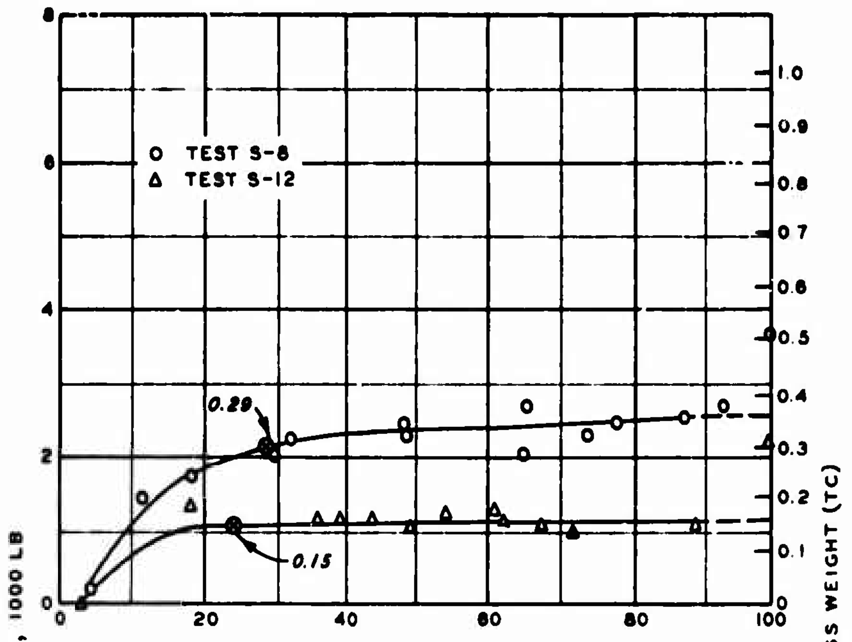
AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC
STRESS BUILDING
PREPARED CH SOIL SURFACE
DRY

PLATE 2B

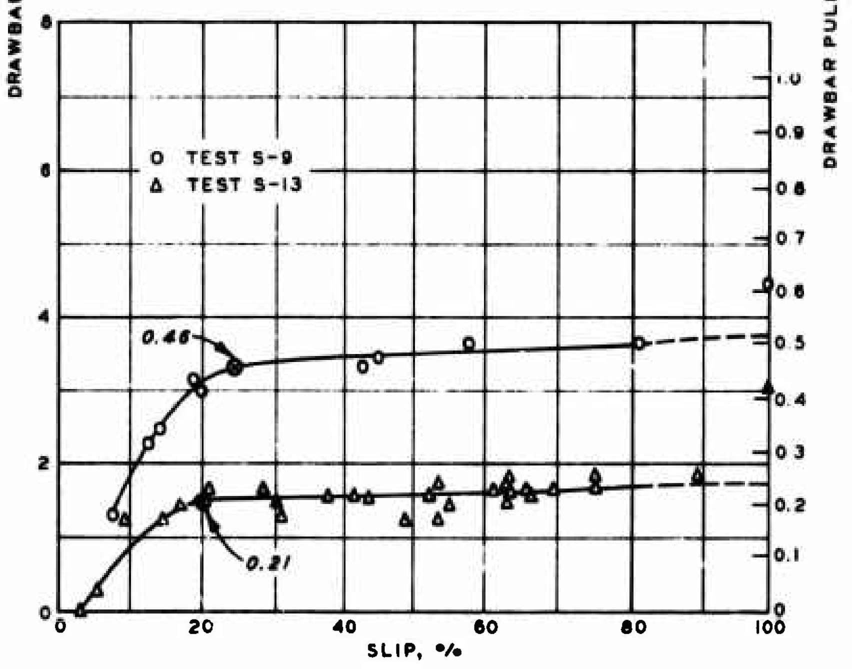


NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38
⊗ DESIGNATES OPT TC
δ DESIGNATES DEFLECTION.

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC
STRESS BUILDING
PREPARED CH SOIL SURFACE
FLOODED



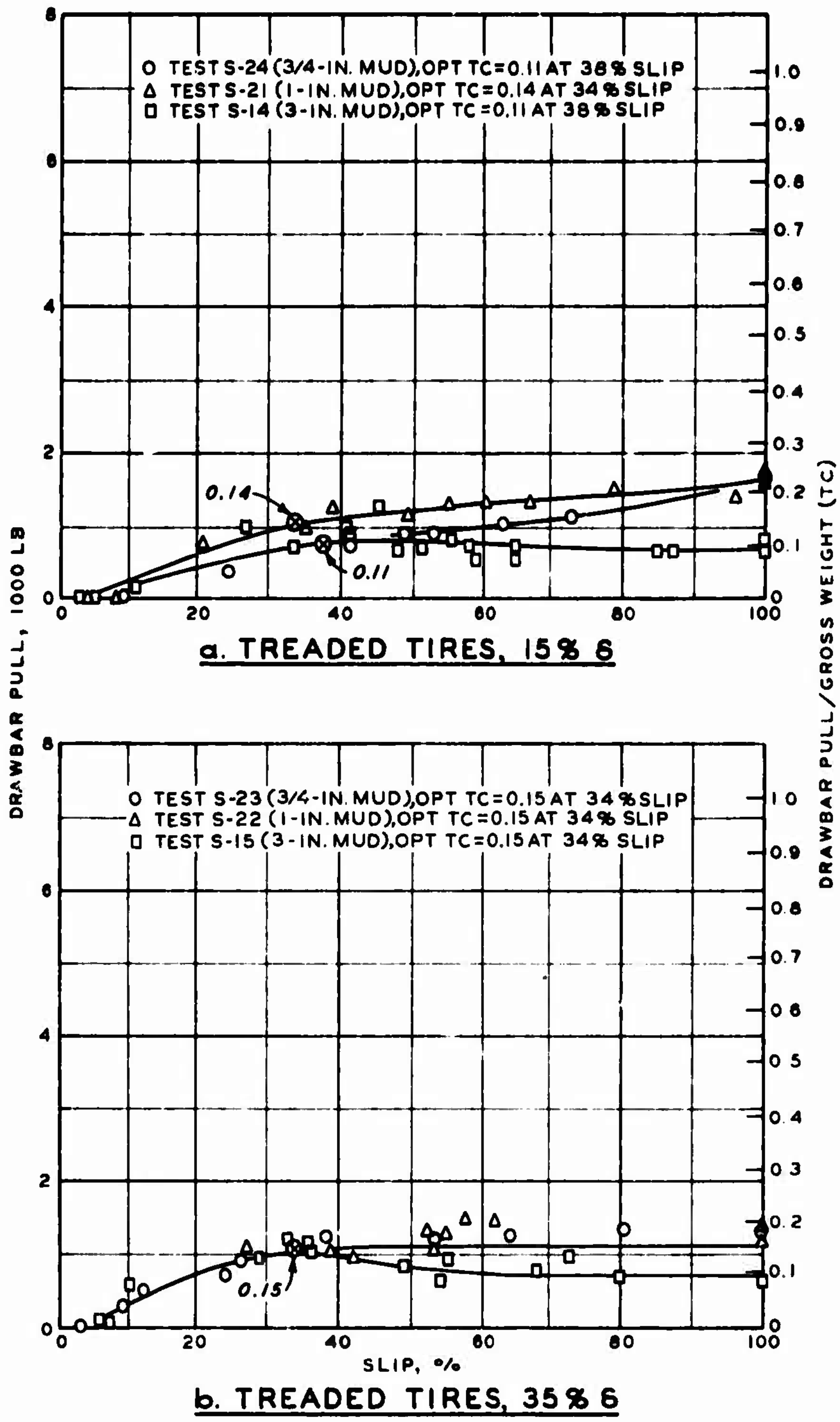
a. TREADED TIRES, 15 % δ



b. TREADED TIRES, 35 % δ

NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC.
δ DESIGNATES DEFLECTION.

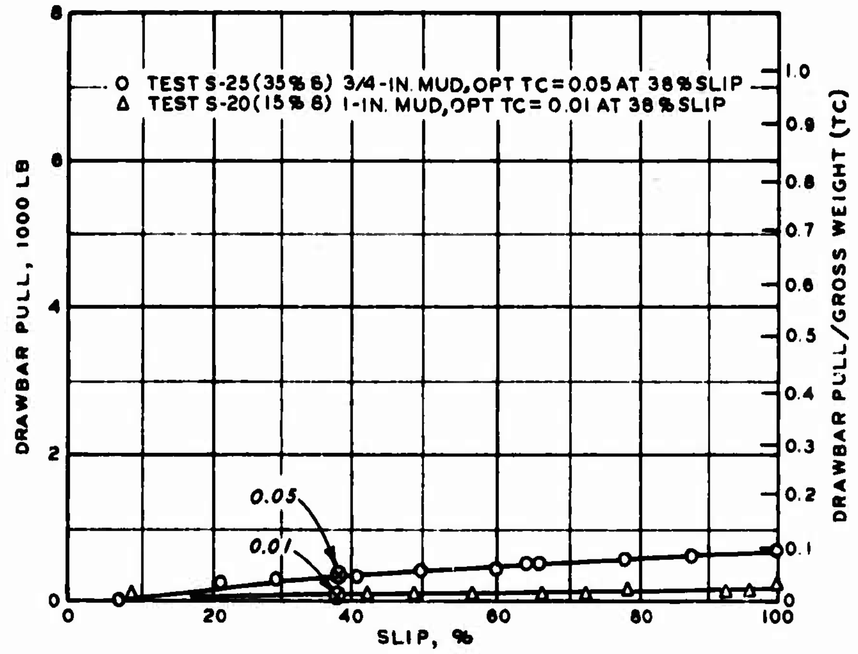
AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC
STRESS BUILDING
PREPARED CH SOIL SURFACE
DRAINED



NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC.
δ DESIGNATES DEFLECTION.

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC
STRESS BUILDING
PREPARED CH SOIL SURFACE
MUD

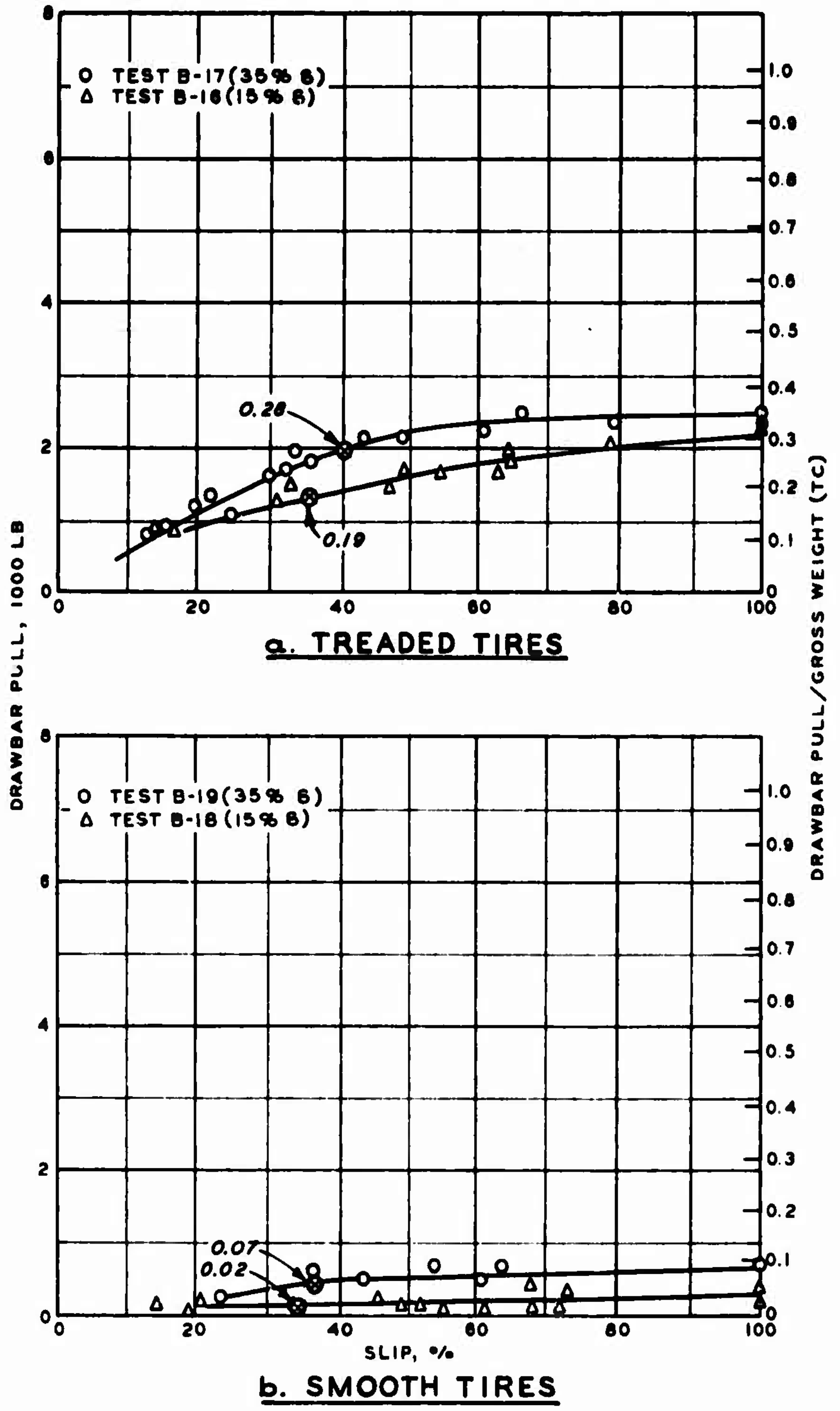
PLATE 5A



c. SMOOTH TIRES

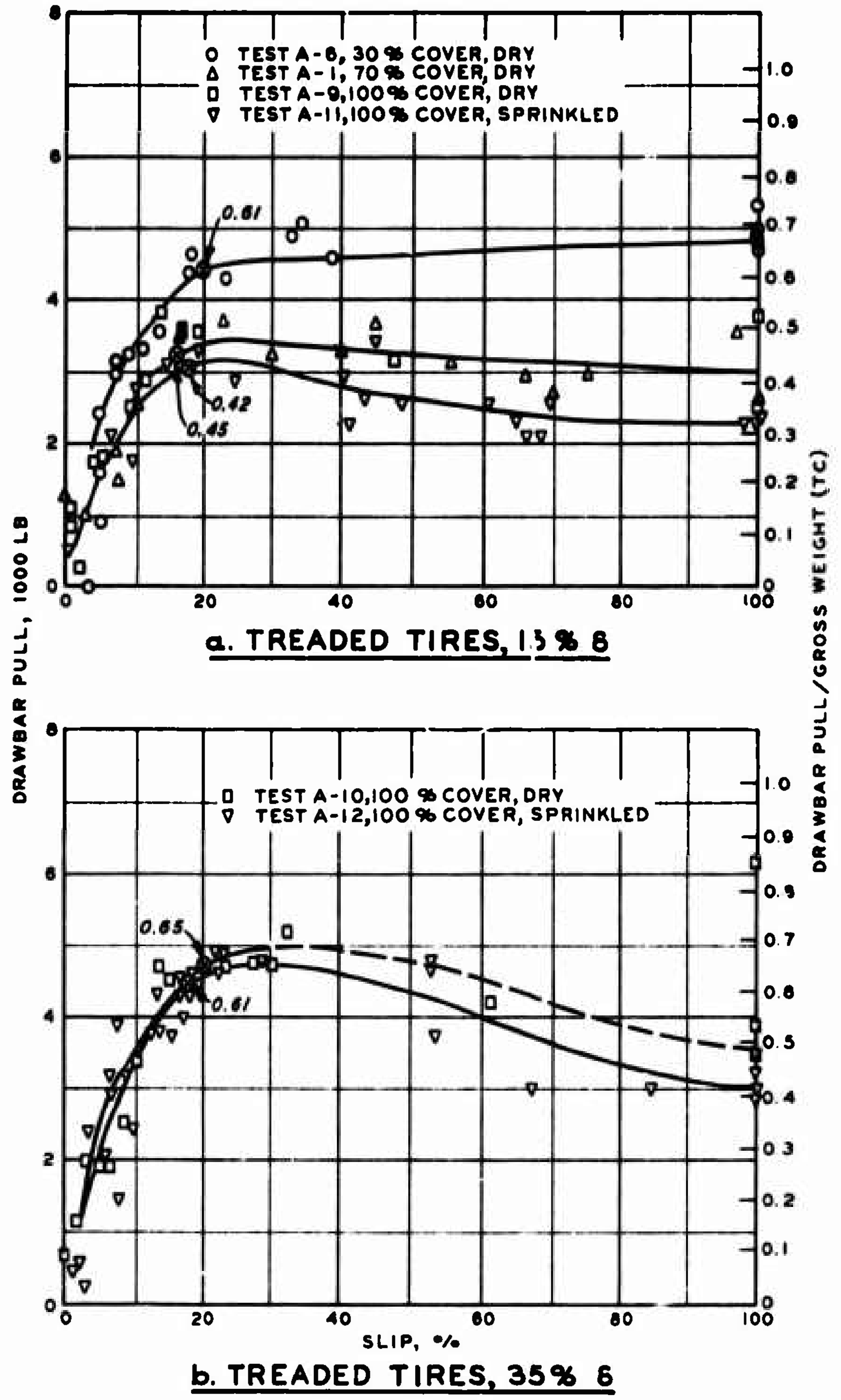
NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC.
δ DESIGNATES DEFLECTION.

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC
STRESS BUILDING
PREPARED CH SOIL SURFACE
MUD



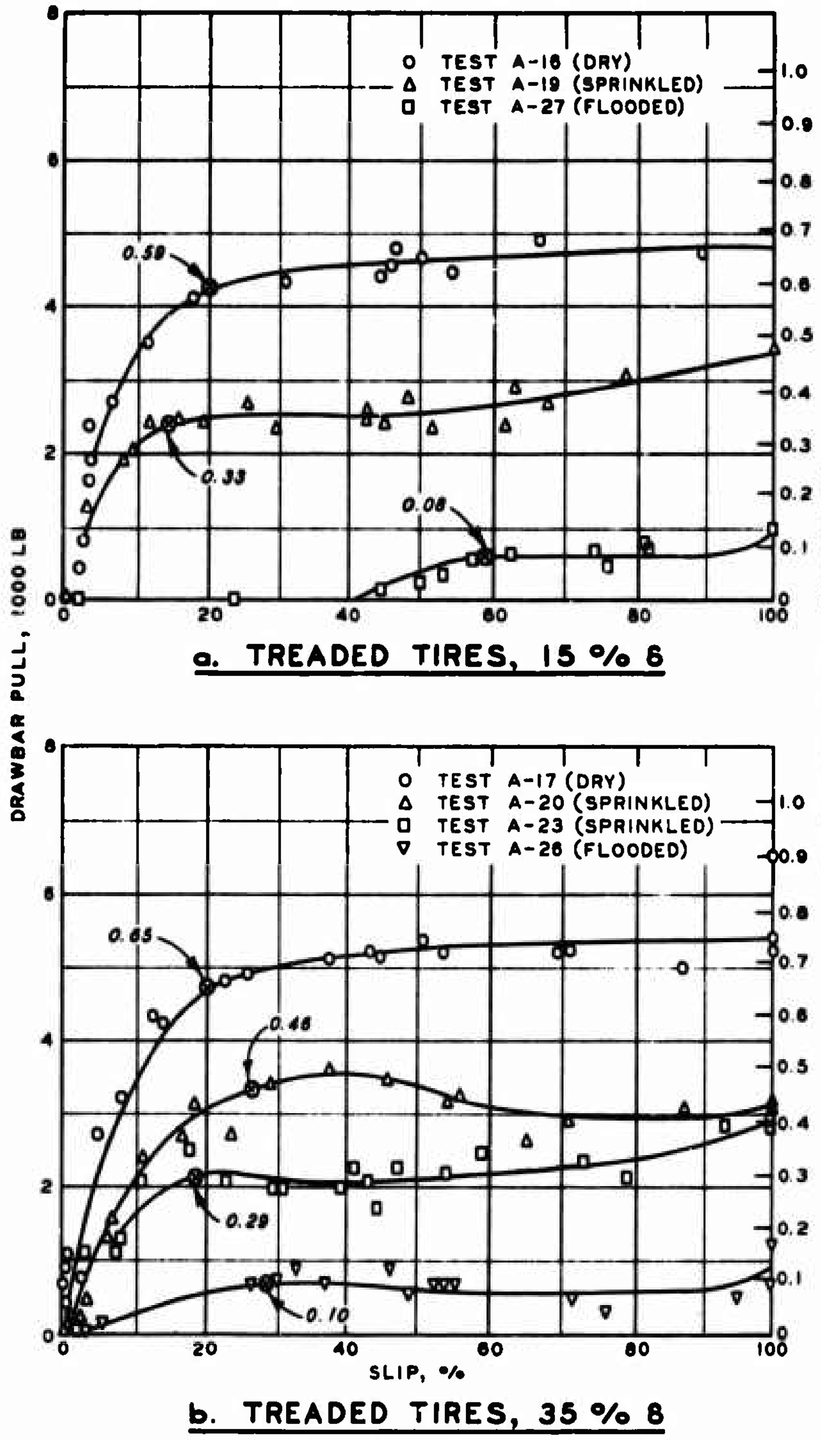
NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC.
δ DESIGNATES DEFLECTION.

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC
HANGAR 4
PREPARED CH SOIL SURFACE
SPRINKLED



NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC.
δ DESIGNATES DEFLECTION.

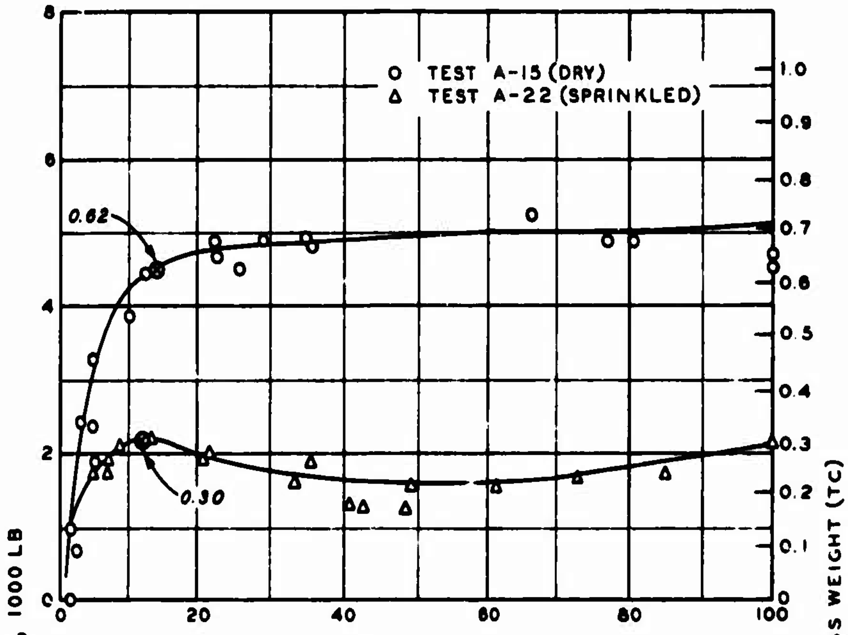
AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC
WES UPLAND FLAT
NATURAL CL/ML SOIL SURFACE
GRASS COVER



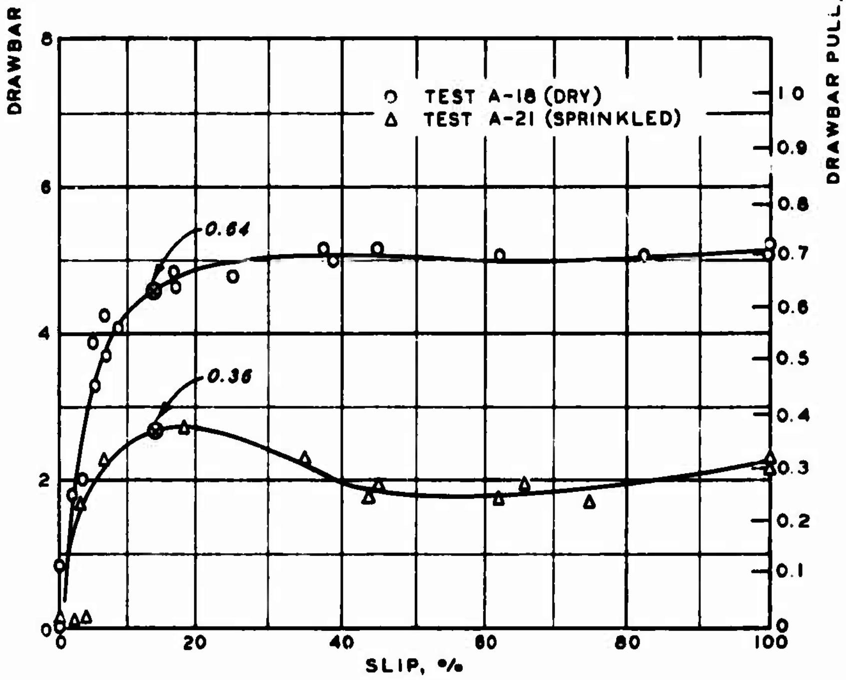
NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC.
δ DESIGNATES DEFLECTION.

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC

WES UPLAND FLAT
PREPARED ML/CL SOIL SURFACE
DRY, SPRINKLED, AND FLOODED



c. SMOOTH TIRES, 15% δ



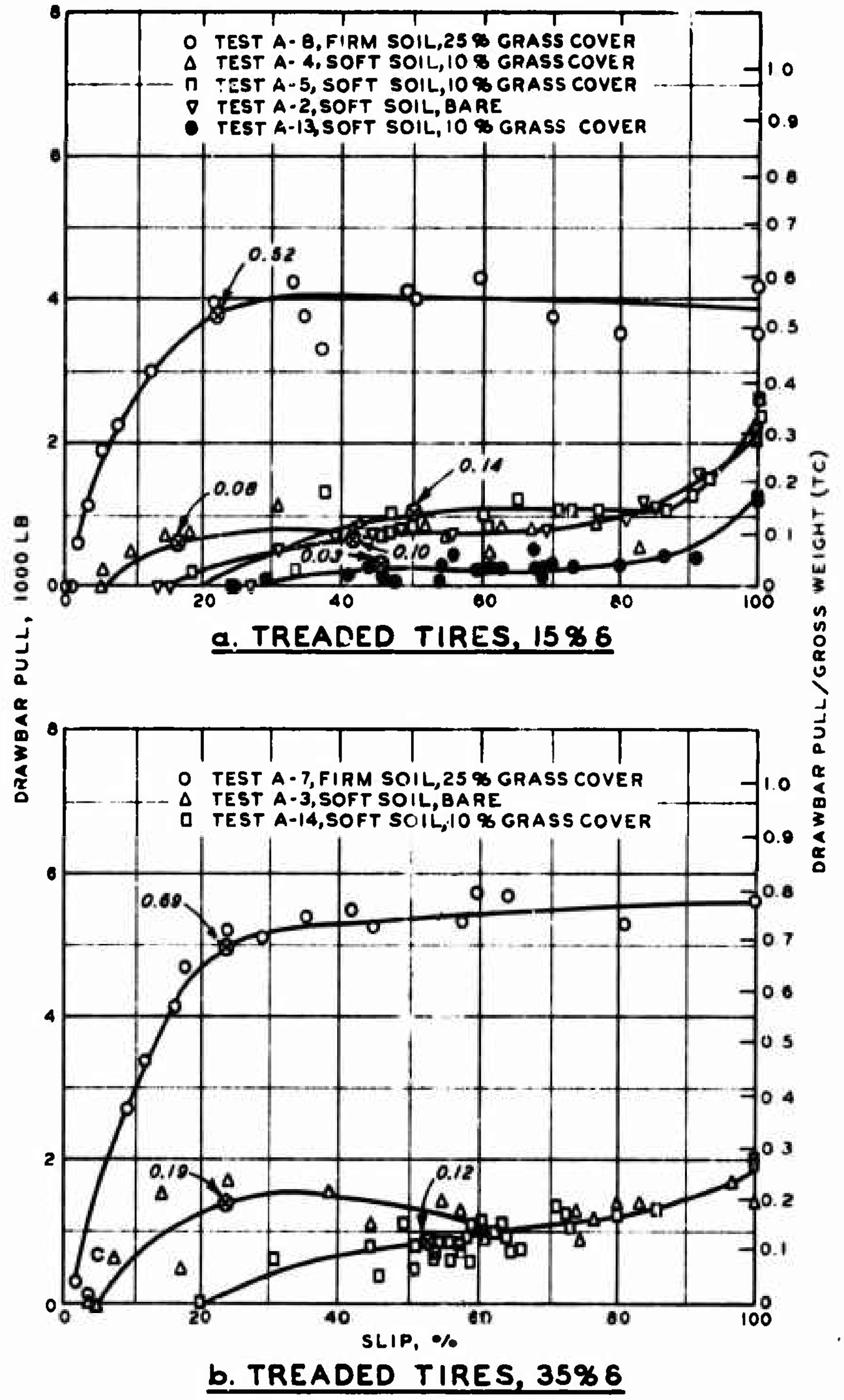
d. SMOOTH TIRES, 35% δ

NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC.
δ DESIGNATES DEFLECTION.

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC

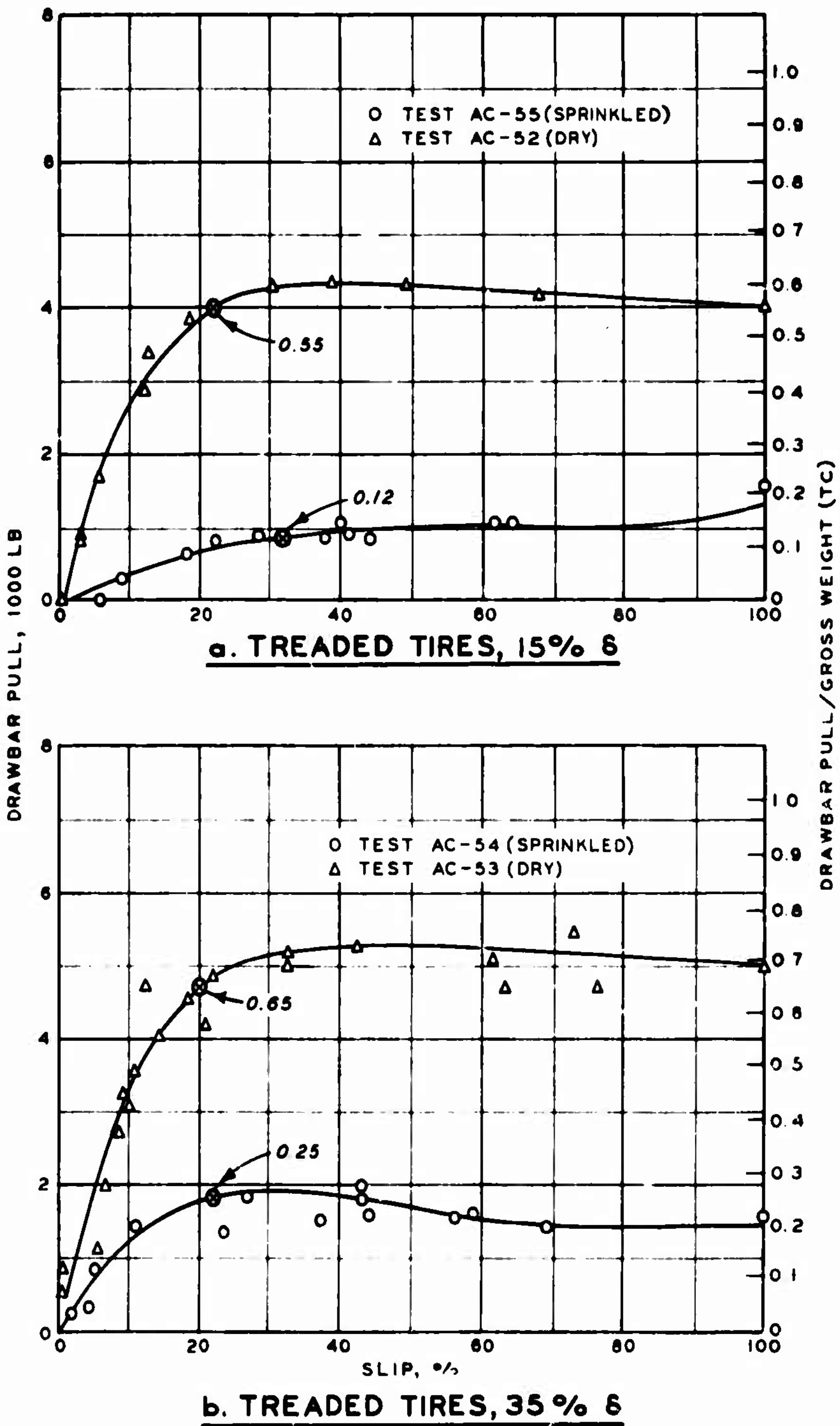
WES UPLAND FLAT PREPARED ML/CL SOIL SURFACE

DRY, SPRINKLED, AND FLOODED



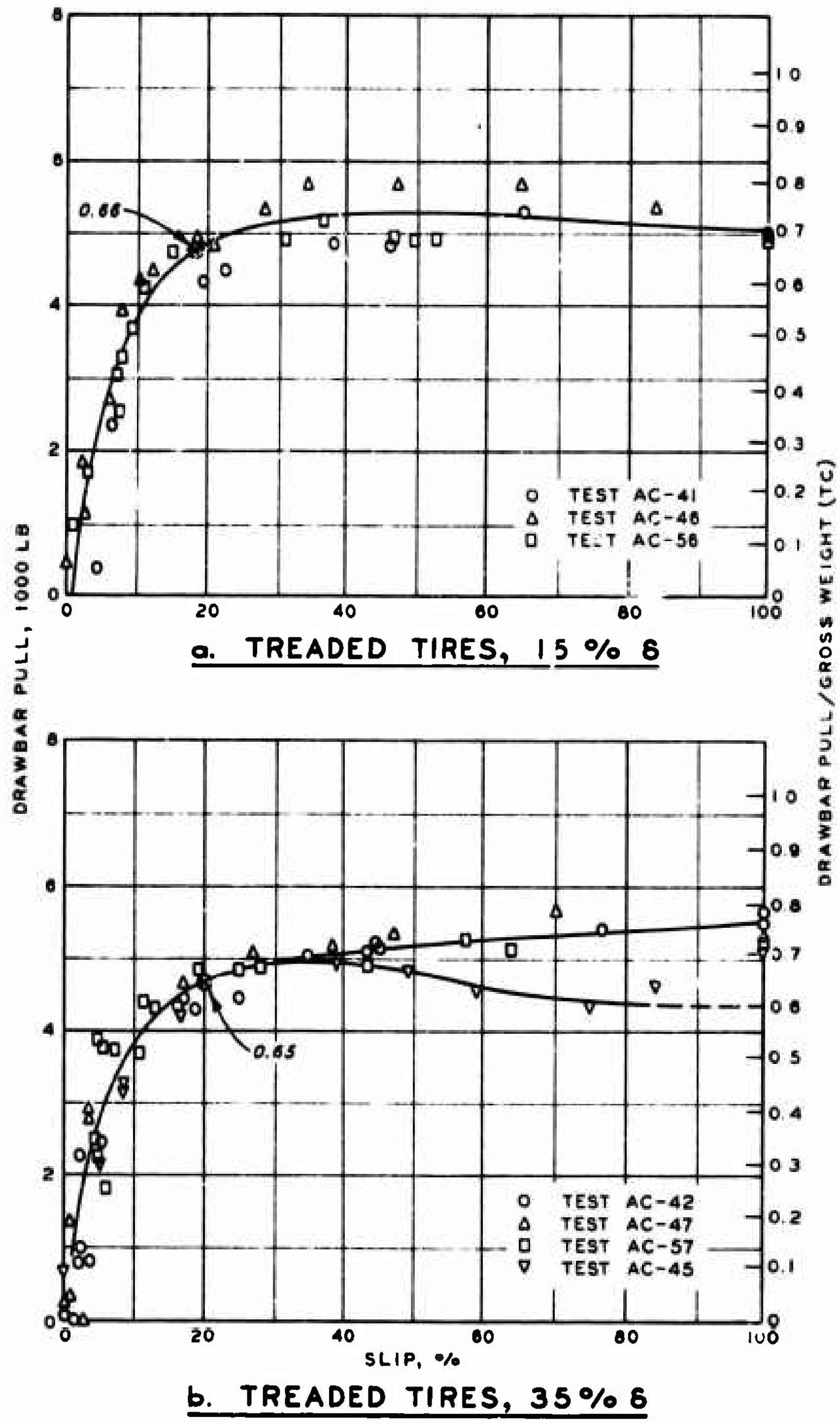
NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC.
δ DESIGNATES DEFLECTION.

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC
WES BOTTOMLAND FLAT
NATURAL CL SOIL SURFACE
BARE AND GRASS COVER



NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38
⊗ DESIGNATES OPT TC
δ DESIGNATES DEFLECTION.

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC
HICKS' FARM
NATURAL CH SOIL SURFACE
GRASS COVER

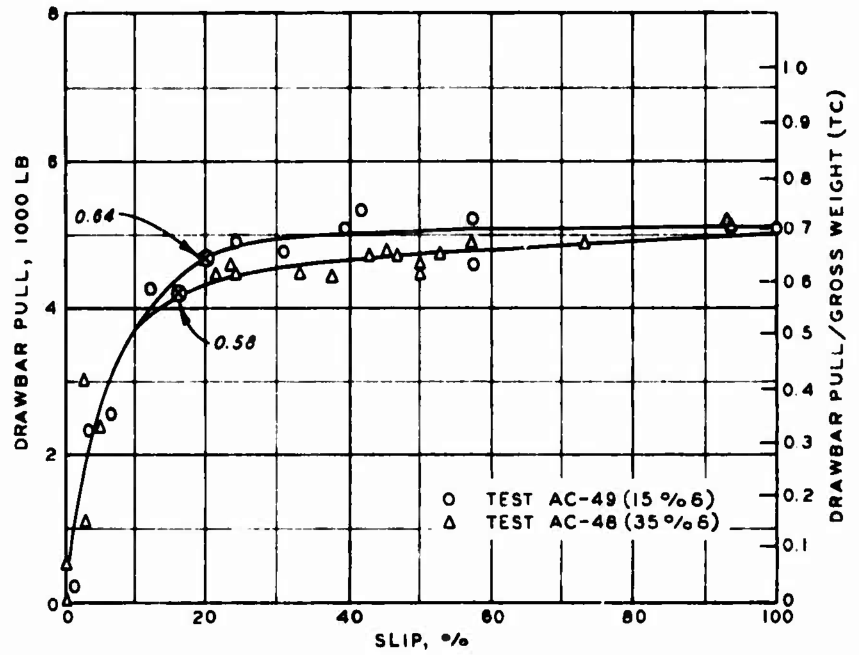


NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC.
δ DESIGNATES DEFLECTION.

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC

HICKS' FARM
PREPARED CH SOIL SURFACE
DRY

PLATE 11A



c. SMOOTH TIRES

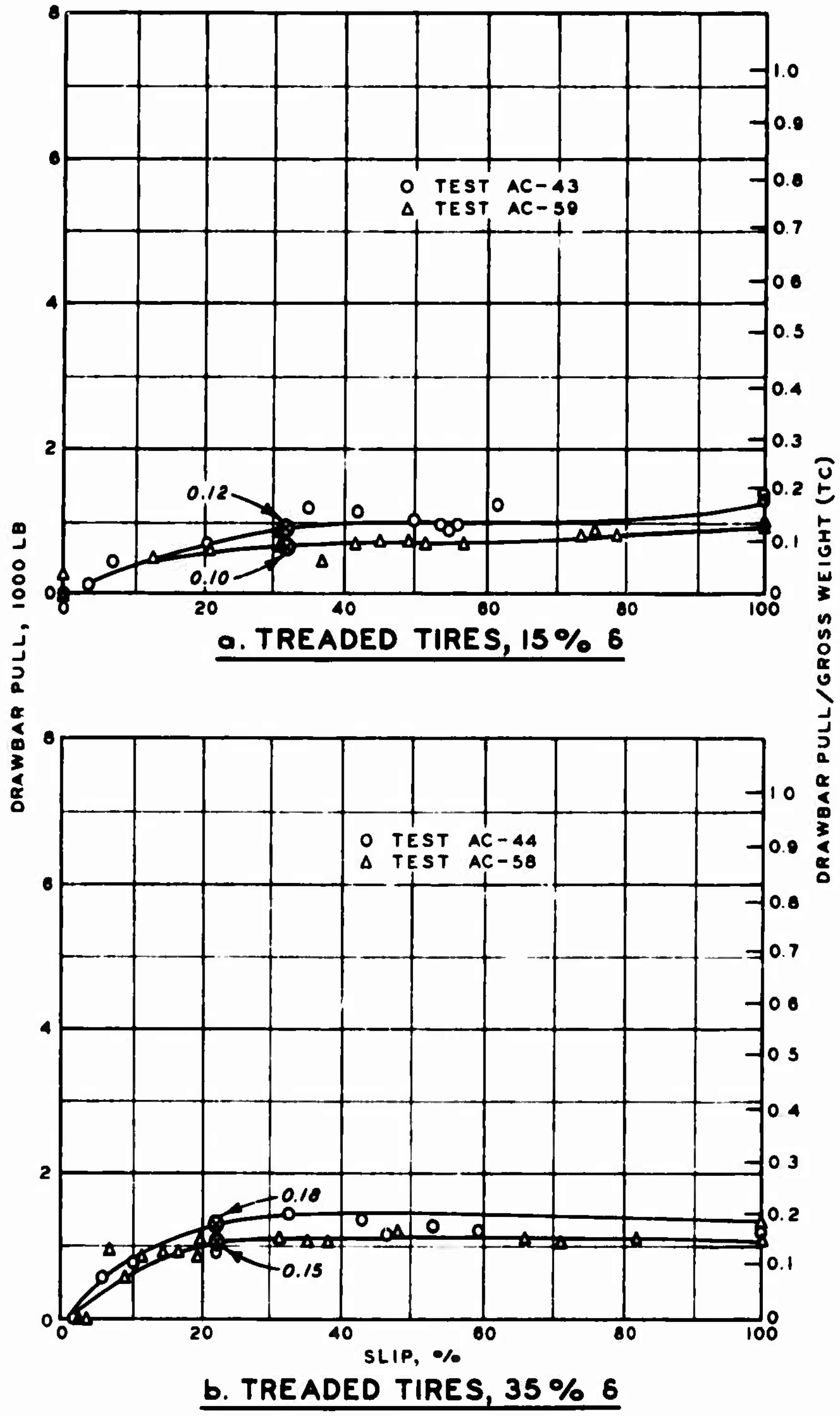
NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC
δ DESIGNATES DEFLECTION.

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC

HICKS' FARM

PREPARED CH SOIL SURFACE

DRY



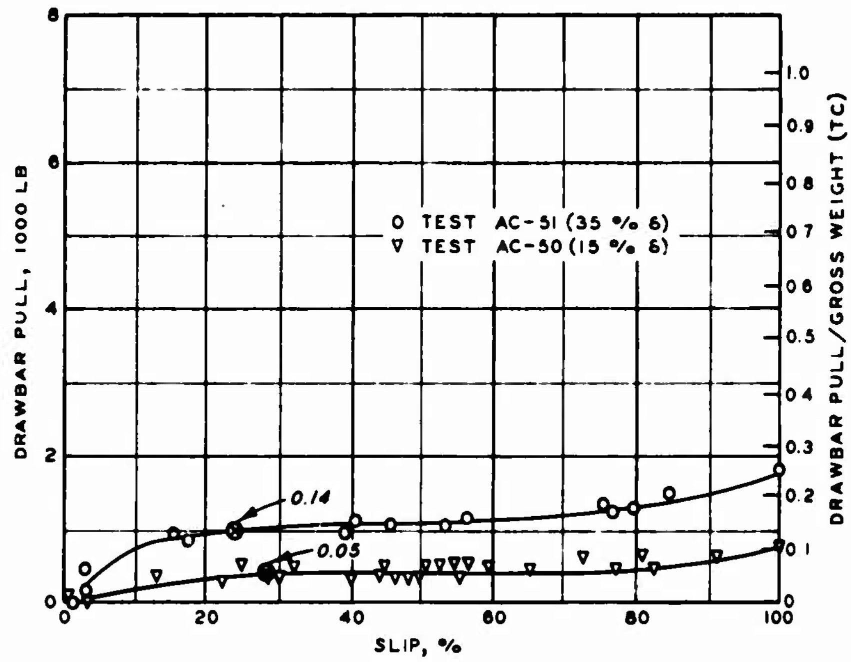
NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC.
δ DESIGNATES DEFLECTION.

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC

HICKS' FARM

PREPARED CH SOIL SURFACE

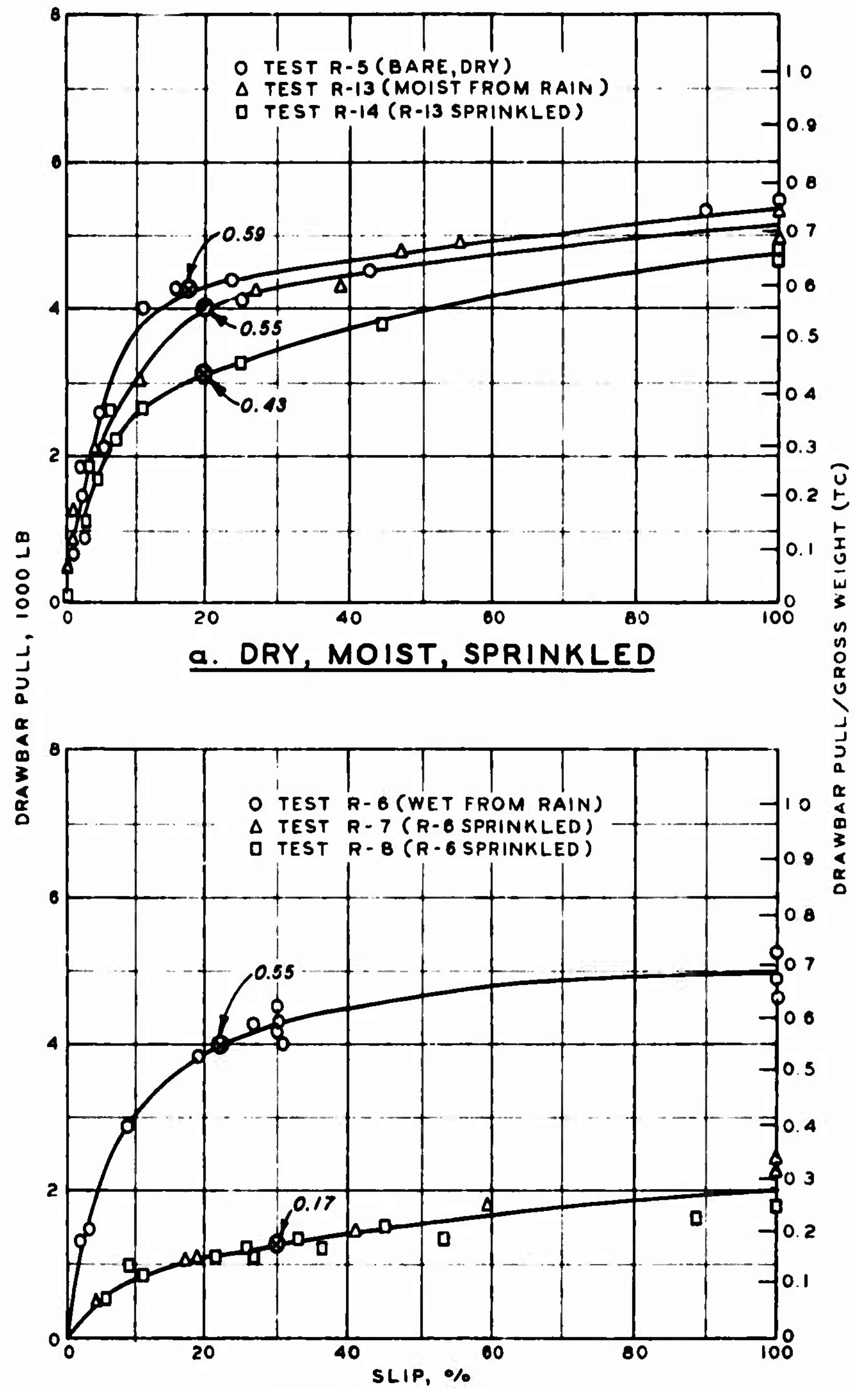
SPRINKLED



c. SMOOTH TIRES

NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC.
δ DESIGNATES DEFLECTION.

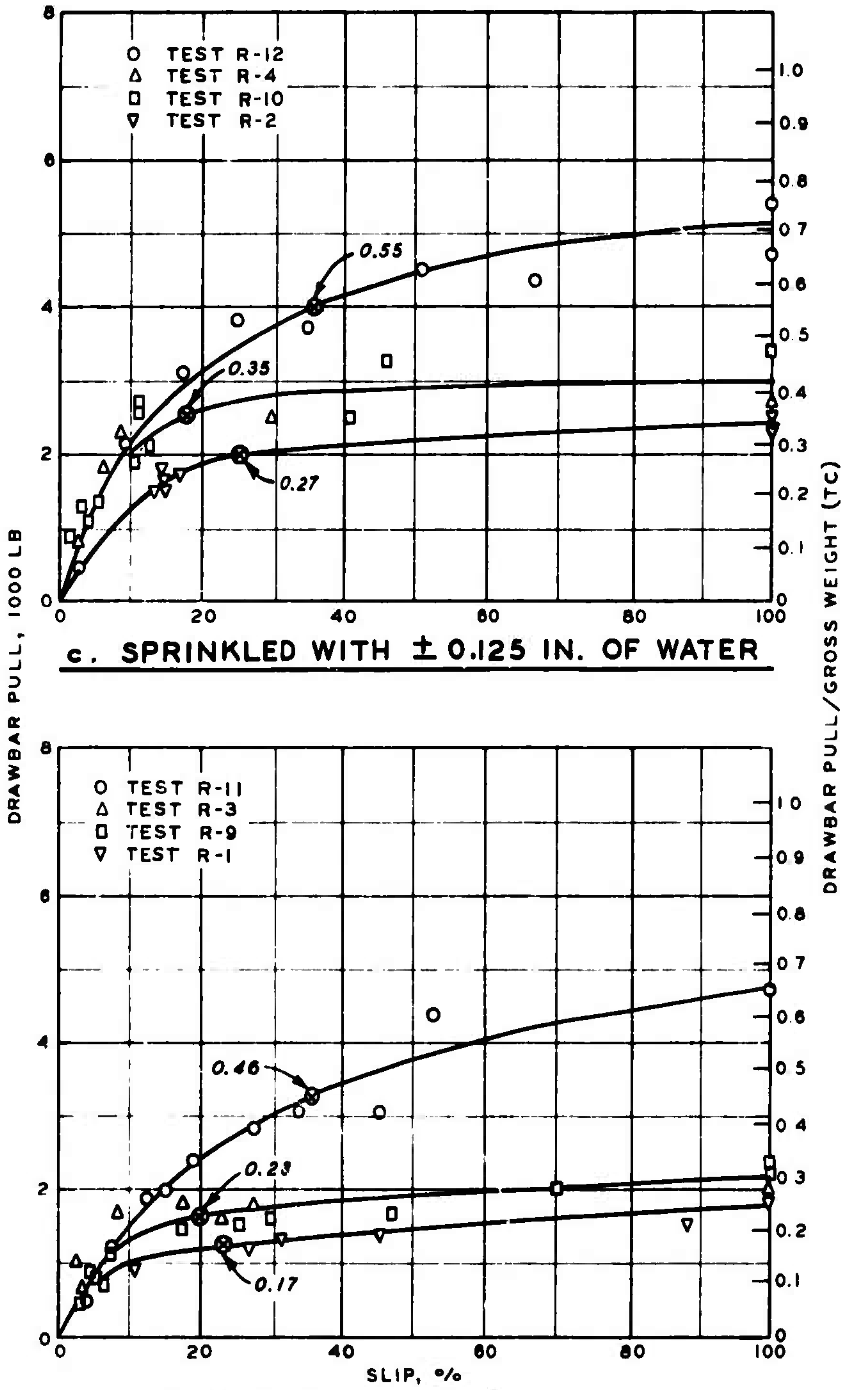
AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC
HICKS' FARM
PREPARED CH SOIL SURFACE
SPRINKLED



b. WETTED, SPRINKLED

NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC
TREADED TIRES, 15% DEFLECTION

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC
SUNFLOWER CANAL ROAD
PREPARED CH SOIL SURFACE
DRY, SPRINKLED, RAIN WETTED

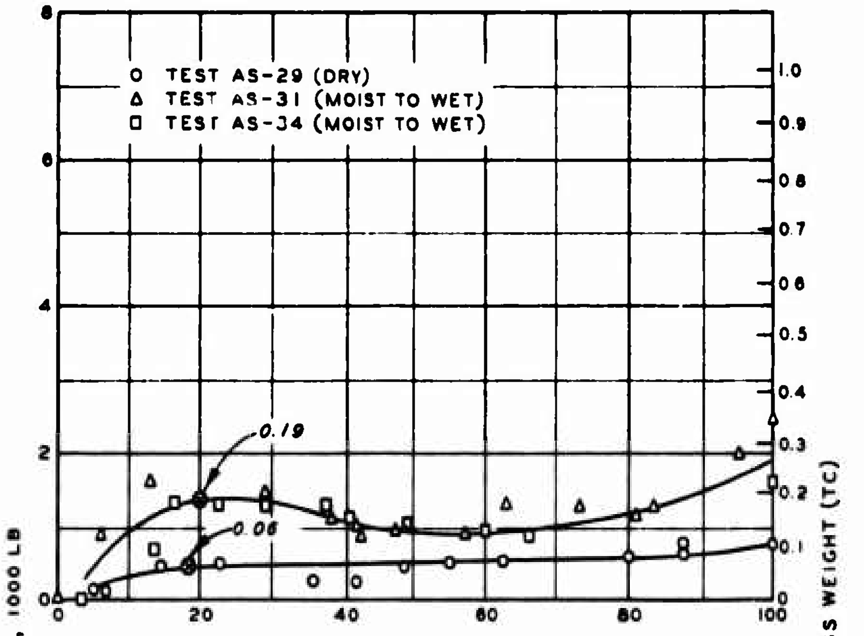


c. SPRINKLED WITH ± 0.125 IN. OF WATER

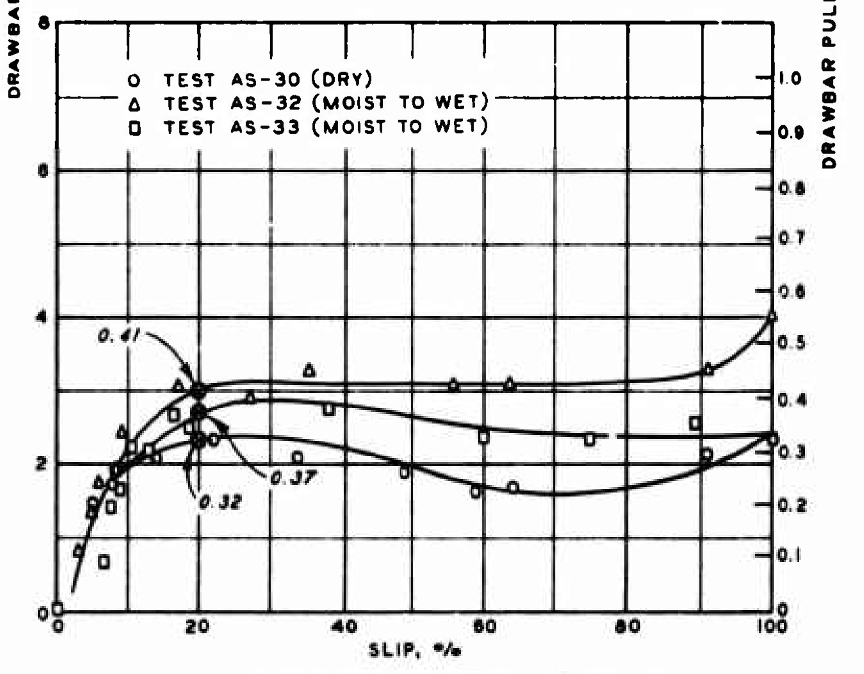
d. SPRINKLED WITH 0.25 IN. OF WATER

NOTE: DATA POINTS READ FROM RECORDER TRACES
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC.
TREADED TIRES, 15 % DEFLECTION

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC
SUNFLOWER CANAL ROAD
PREPARED CH SOIL SURFACE
DRY, SPRINKLED, RAIN WETTED



a. TREADED TIRES, 15 % δ



b. TREADED TIRES, 35 % δ

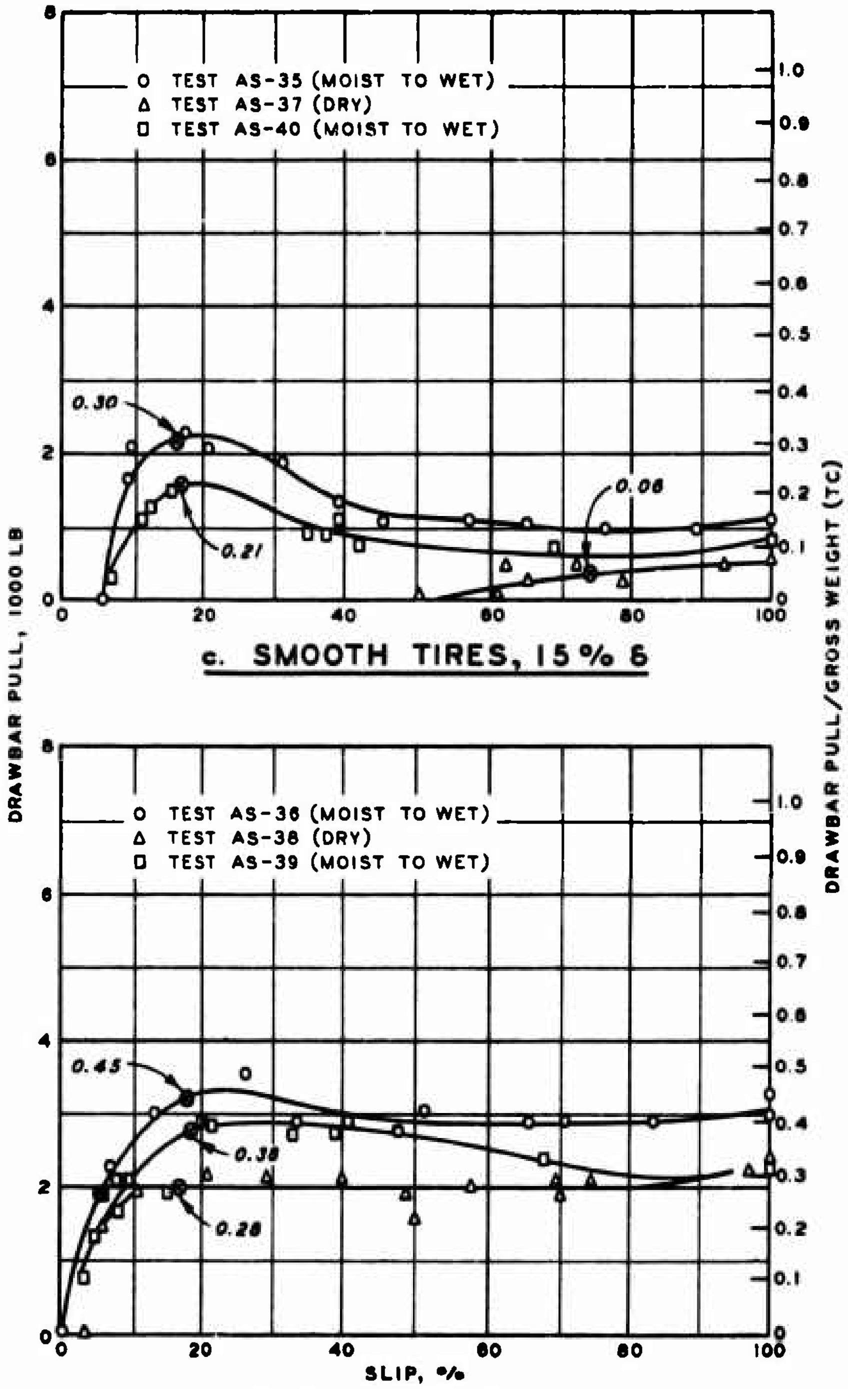
NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊕ DESIGNATES OPT TC.
δ DESIGNATES DEFLECTION.

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC

MISSISSIPPI RIVER BEACH NATURAL SP SOIL SURFACE

DRY, MOIST, AND WET

BARE



c. SMOOTH TIRES, 15% δ

d. SMOOTH TIRES, 35% δ

NOTE: DATA POINTS READ FROM RECORDER TRACES.
OPT TC VALUES DETERMINED AS SHOWN IN PARAGRAPH 38.
⊗ DESIGNATES OPT TC.
δ DESIGNATES DEFLECTION.

AVG DRAWBAR PULL-SLIP RELATIONS AND OPT TC
MISSISSIPPI RIVER BEACH NATURAL SP SOIL SURFACE
DRY, MOIST, AND WET
BARE

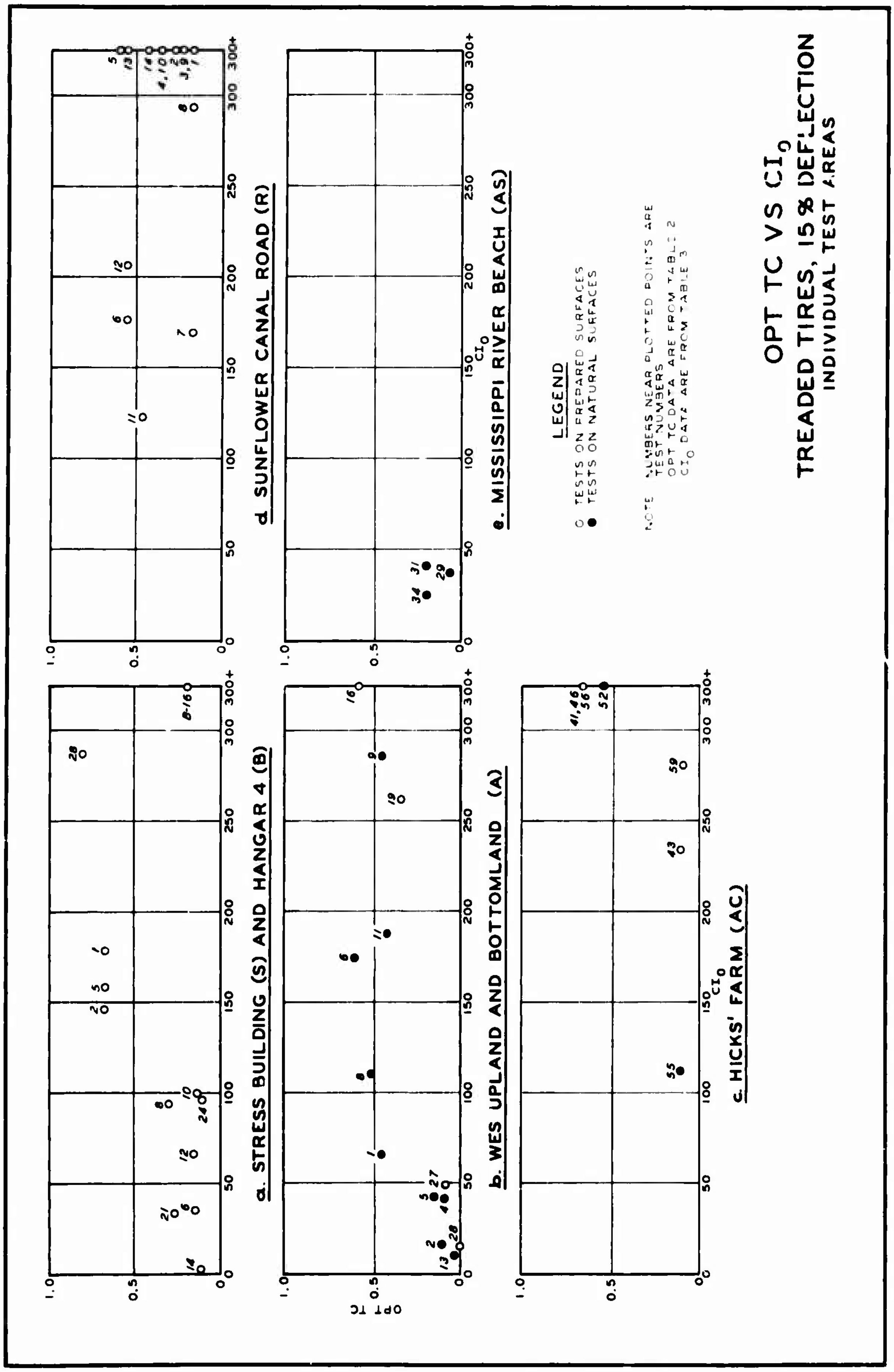
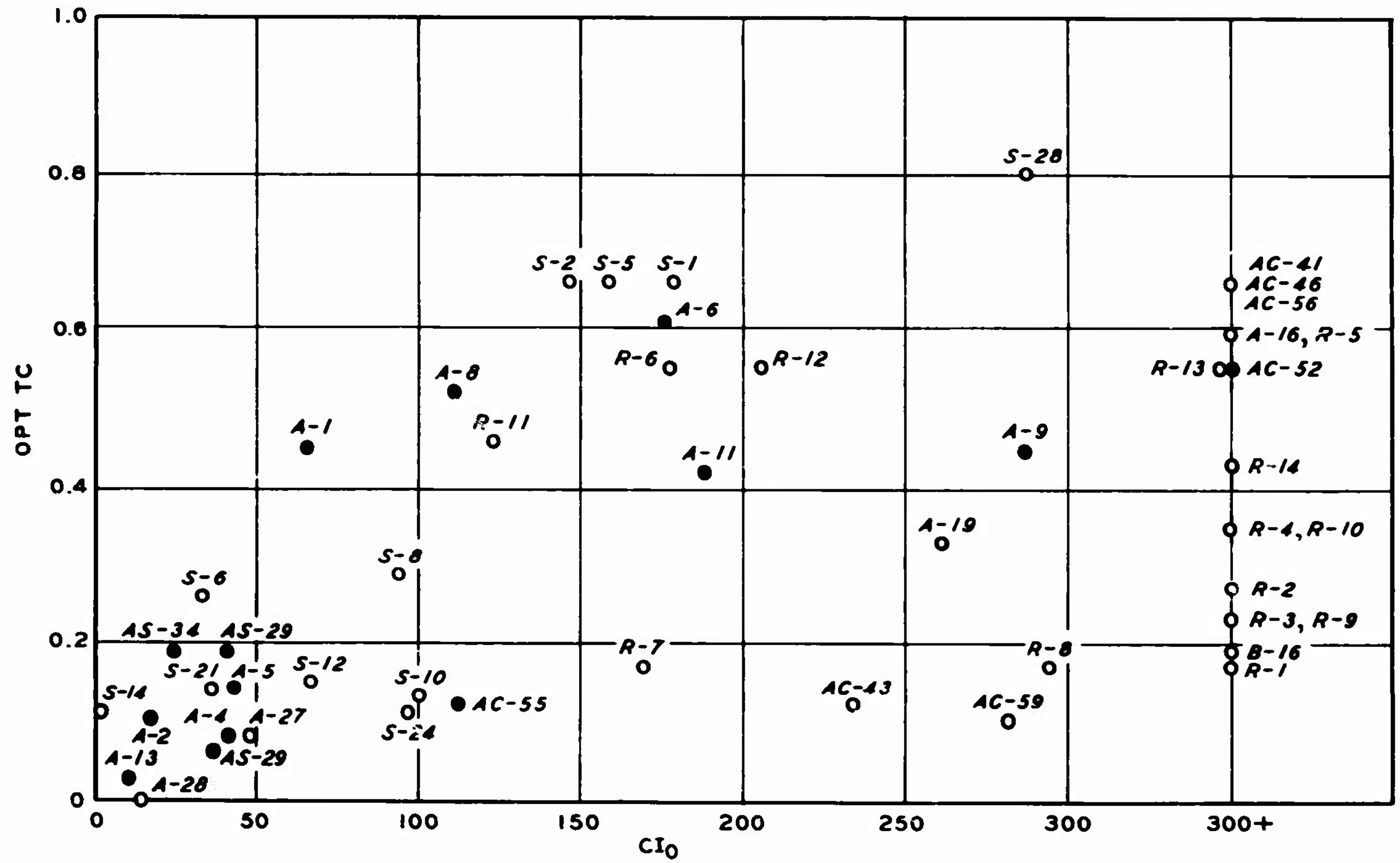

OPT TC VS CI0
TREADED TIRES, 15% DEFLECTION
INDIVIDUAL TEST AREAS
a. STRESS BUILDING (S) AND HANGAR 4 (B)
b. WES UPLAND AND BOTTOMLAND (A)
c. HICKS' FARM (AC)
d. SUNFLOWER CANAL ROAD (R)
e. MISSISSIPPI RIVER BEACH (AS)
LEGEND
TESTS ON PREPARED SURFACES
TESTS ON NATURAL SURFACES
NOTE NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS
OPT TC DATA ARE FROM TABLE 2
CI0 DATA ARE FROM TABLE 3
OPT TC
CI0

PLATE 15



NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS. LETTERS PRECEDING TEST NUMBERS IDENTIFY TEST AREAS. OPEN SYMBOLS DENOTE PREPARED SURFACES; CLOSED SYMBOLS DENOTE NATURAL SURFACES.

OPT TC VS CI_O

TREADED TIRES, 15% DEFLECTION

ALL DATA

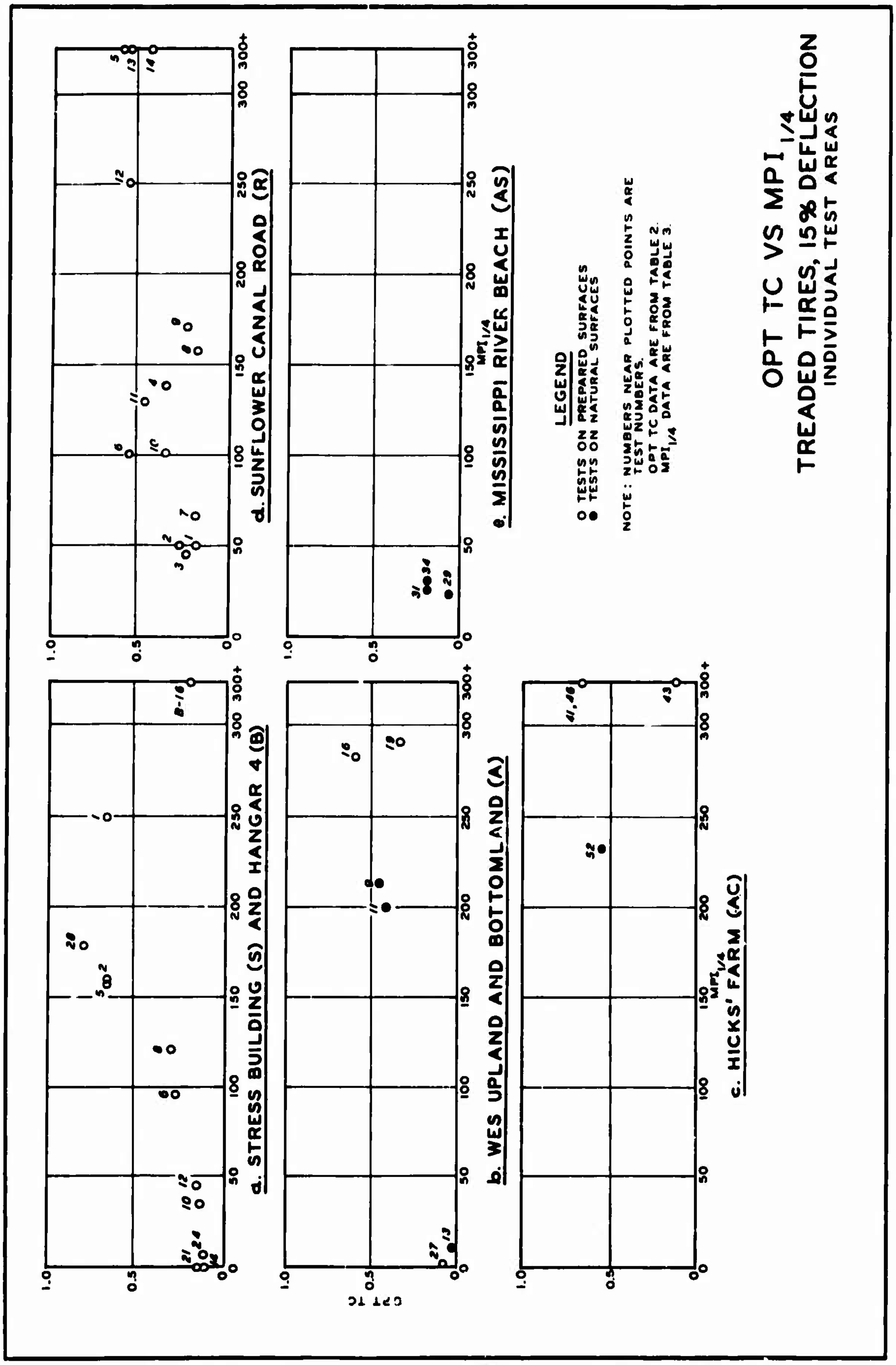
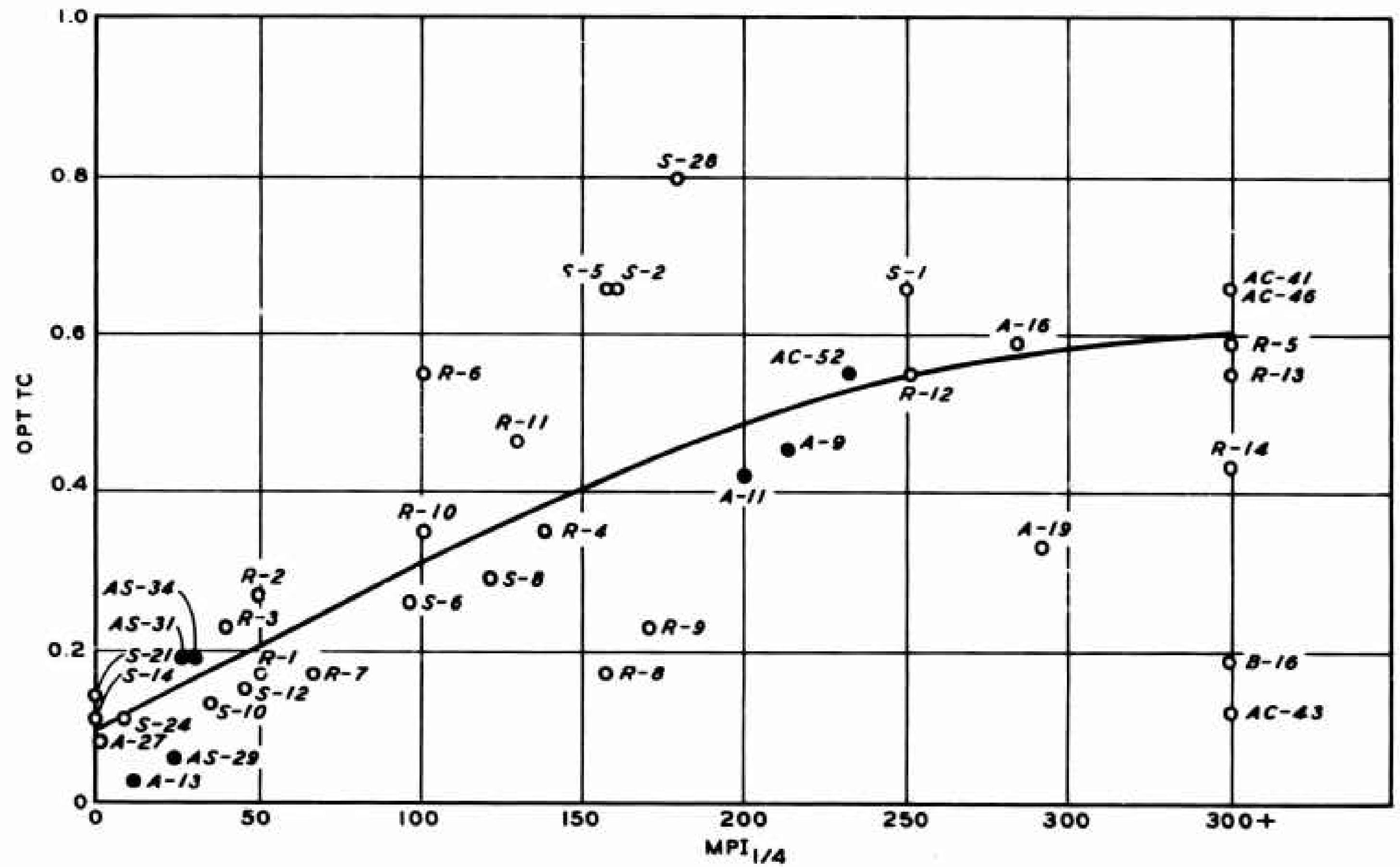

OPT TC VS MPI 1/4
TREADED TIRES, 15% DEFLECTION
INDIVIDUAL TEST AREAS
a. STRESS BUILDING (S) AND HANGAR 4 (B)
b. WES UPLAND AND BOTTOMLAND (A)
c. HICKS' FARM (AC)
d. SUNFLOWER CANAL ROAD (R)
e. MISSISSIPPI RIVER BEACH (AS)
OPT TC
MPI 1/4
LEGEND
O TESTS ON PREPARED SURFACES
● TESTS ON NATURAL SURFACES
NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
OPT TC DATA ARE FROM TABLE 2.
MPI 1/4 DATA ARE FROM TABLE 3.

PLATE 17



NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS. LETTERS PRECEDING TEST NUMBERS IDENTIFY TEST AREAS. OPEN SYMBOLS DENOTE PREPARED SURFACES; CLOSED SYMBOLS DENOTE NATURAL SURFACES.

OPT TC VS $MPI_{1/4}$

TREADED TIRES, 15% DEFLECTION

ALL DATA

PLATE 18

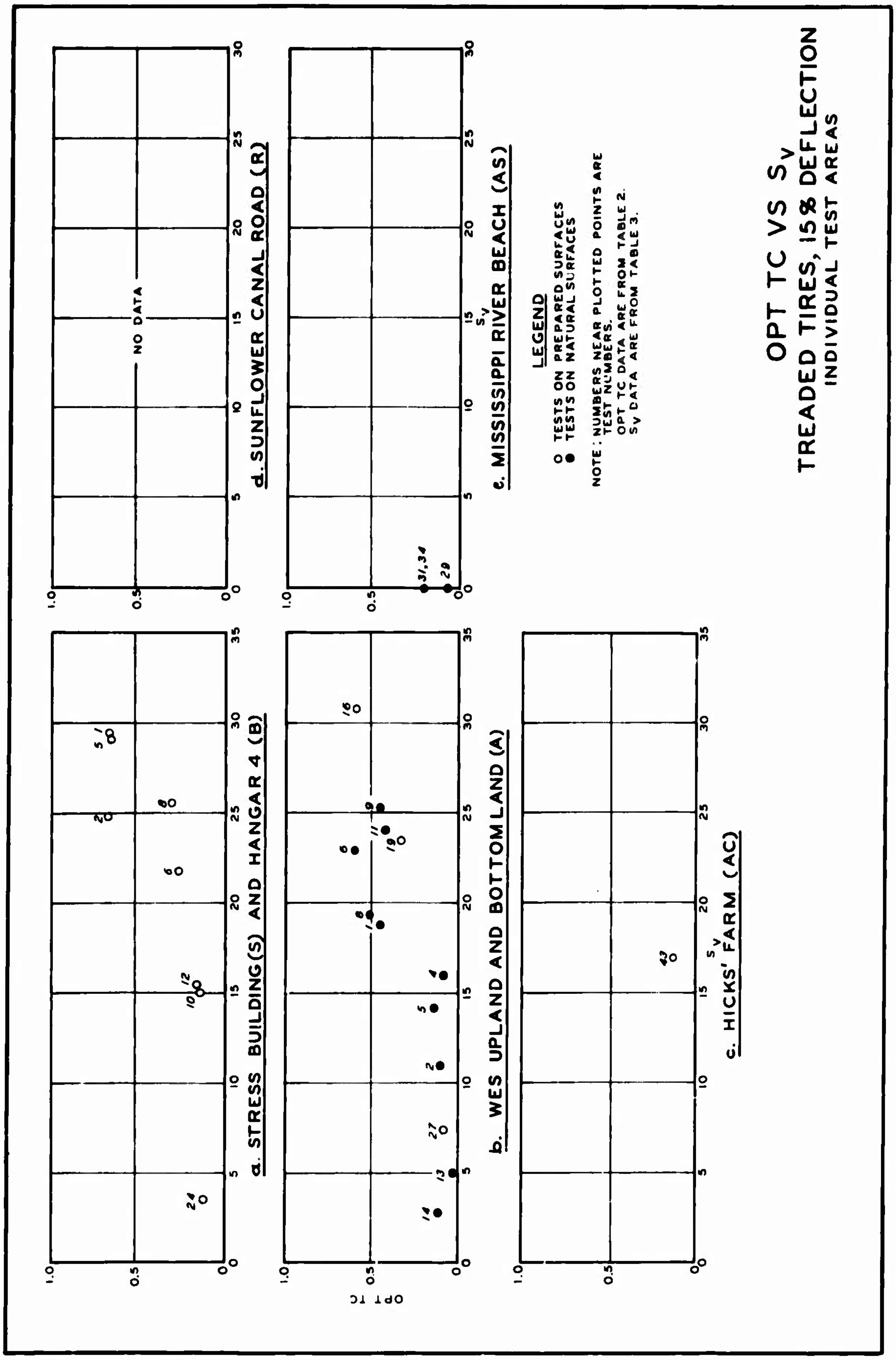
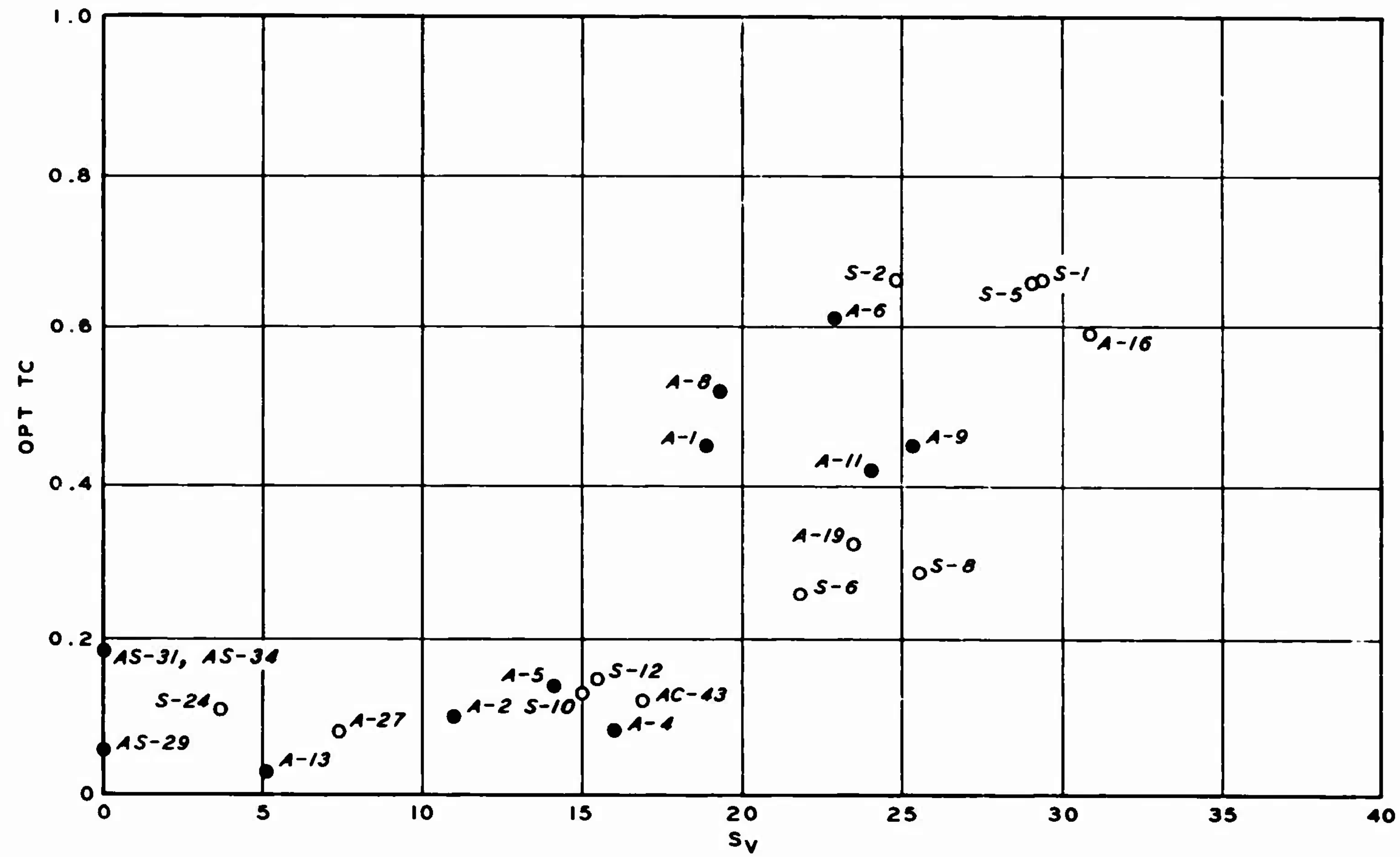

OPT TC VS S_V
TREADED TIRES, 15% DEFLECTION
INDIVIDUAL TEST AREAS
a. STRESS BUILDING(S) AND HANGAR 4 (B)
b. WES UPLAND AND BOTTOMLAND (A)
c. HICKS' FARM (AC)
d. SUNFLOWER CANAL ROAD (R)
NO DATA
e. MISSISSIPPI RIVER BEACH (AS)
OPT TC
S_V
LEGEND
O TESTS ON PREPARED SURFACES
● TESTS ON NATURAL SURFACES
NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
OPT TC DATA ARE FROM TABLE 2.
S_V DATA ARE FROM TABLE 3.

PLATE 19

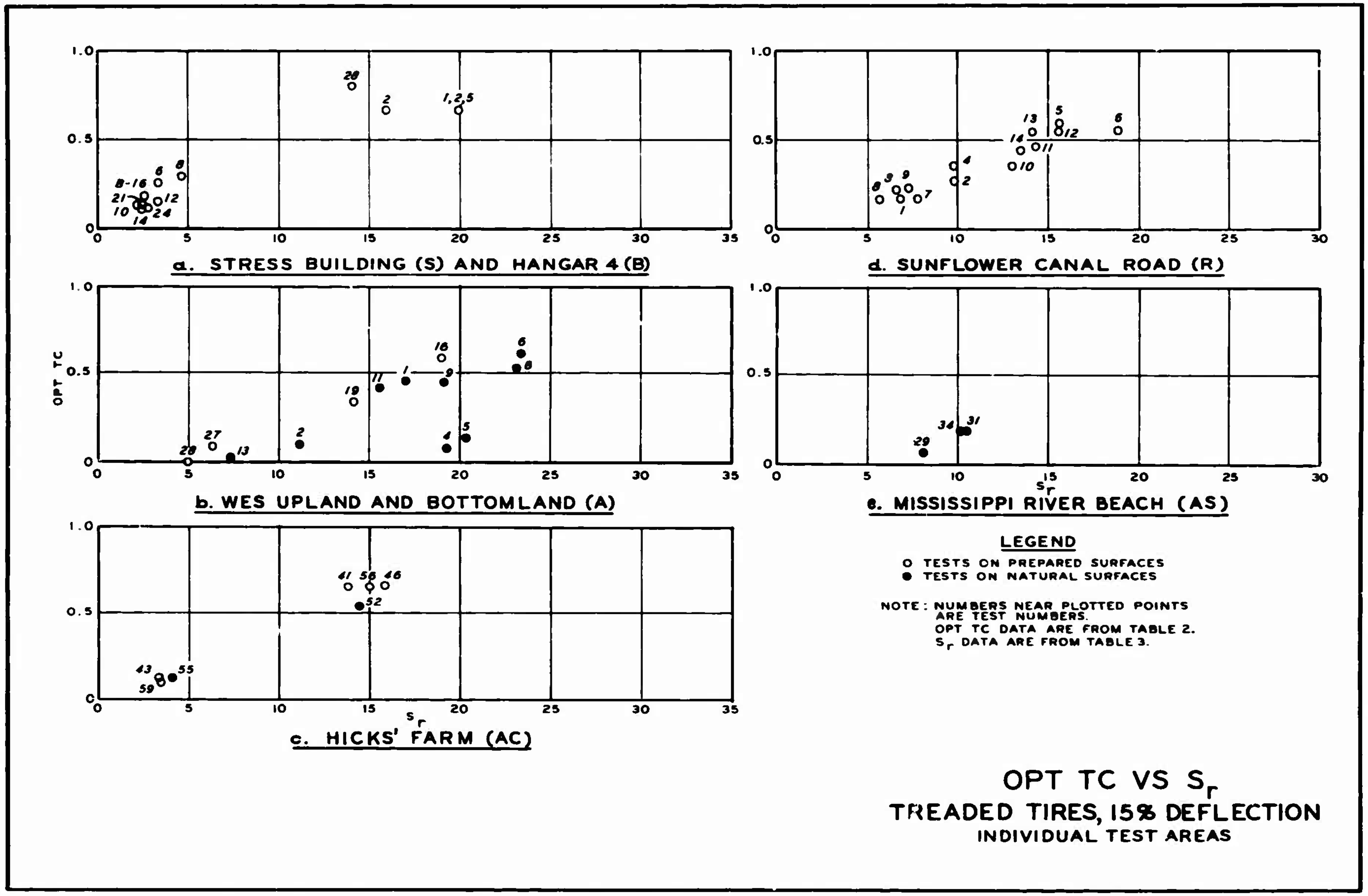


NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
LETTERS PRECEDING TEST NUMBERS IDENTIFY TEST AREAS.
OPEN SYMBOLS DENOTE PREPARED SURFACES; CLOSED SYMBOLS DENOTE NATURAL SURFACES.

OPT TC VS S_V

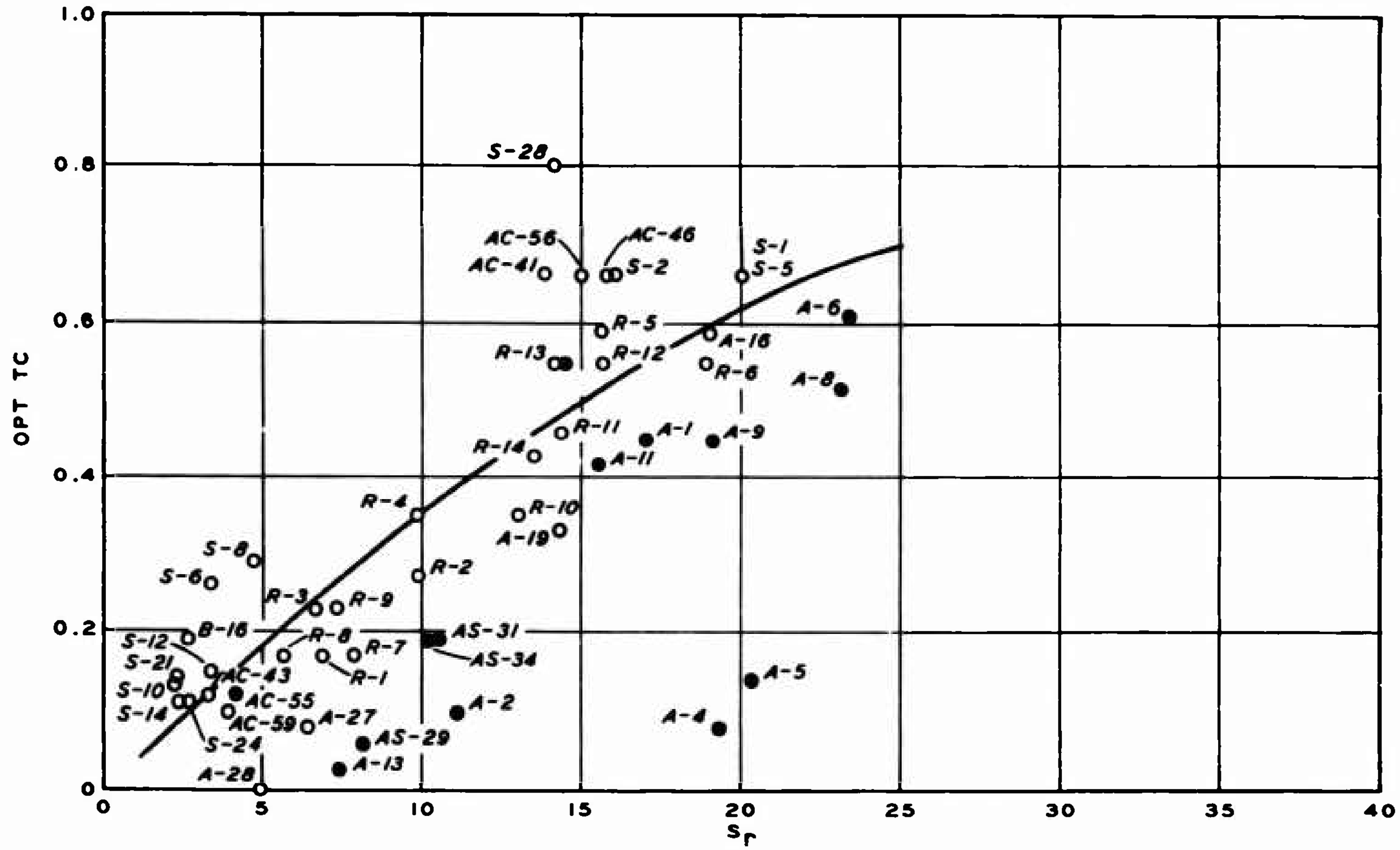
TREADED TIRES, 15% DEFLECTION

ALL DATA



a. STRESS BUILDING (S) AND HANGAR 4 (B)
b. WES UPLAND AND BOTTOMLAND (A)
c. HICKS' FARM (AC)
d. SUNFLOWER CANAL ROAD (R)
e. MISSISSIPPI RIVER BEACH (AS)
OPT TC
S_r
LEGEND
O TESTS ON PREPARED SURFACES
● TESTS ON NATURAL SURFACES
NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
OPT TC DATA ARE FROM TABLE 2.
S_r DATA ARE FROM TABLE 3.
OPT TC VS S_r
TREADED TIRES, 15% DEFLECTION
INDIVIDUAL TEST AREAS

PLATE 21



NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
LETTERS PRECEDING TEST NUMBERS IDENTIFY TEST AREAS.
OPEN SYMBOLS DENOTE PREPARED SURFACES; CLOSED SYMBOLS DENOTE NATURAL SURFACES.

OPT TC VS S_r

TREADED TIRES, 15% DEFLECTION

ALL DATA

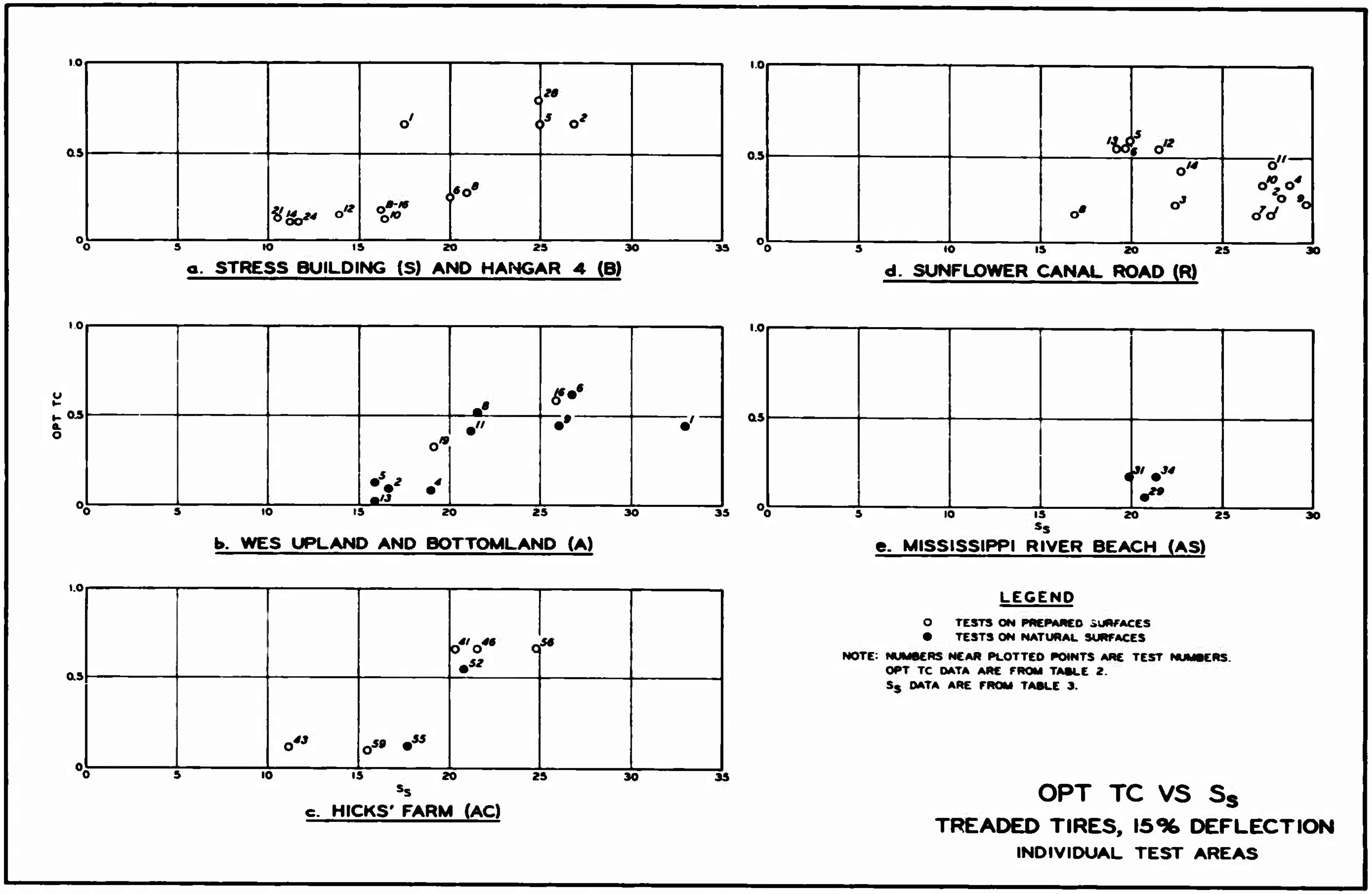
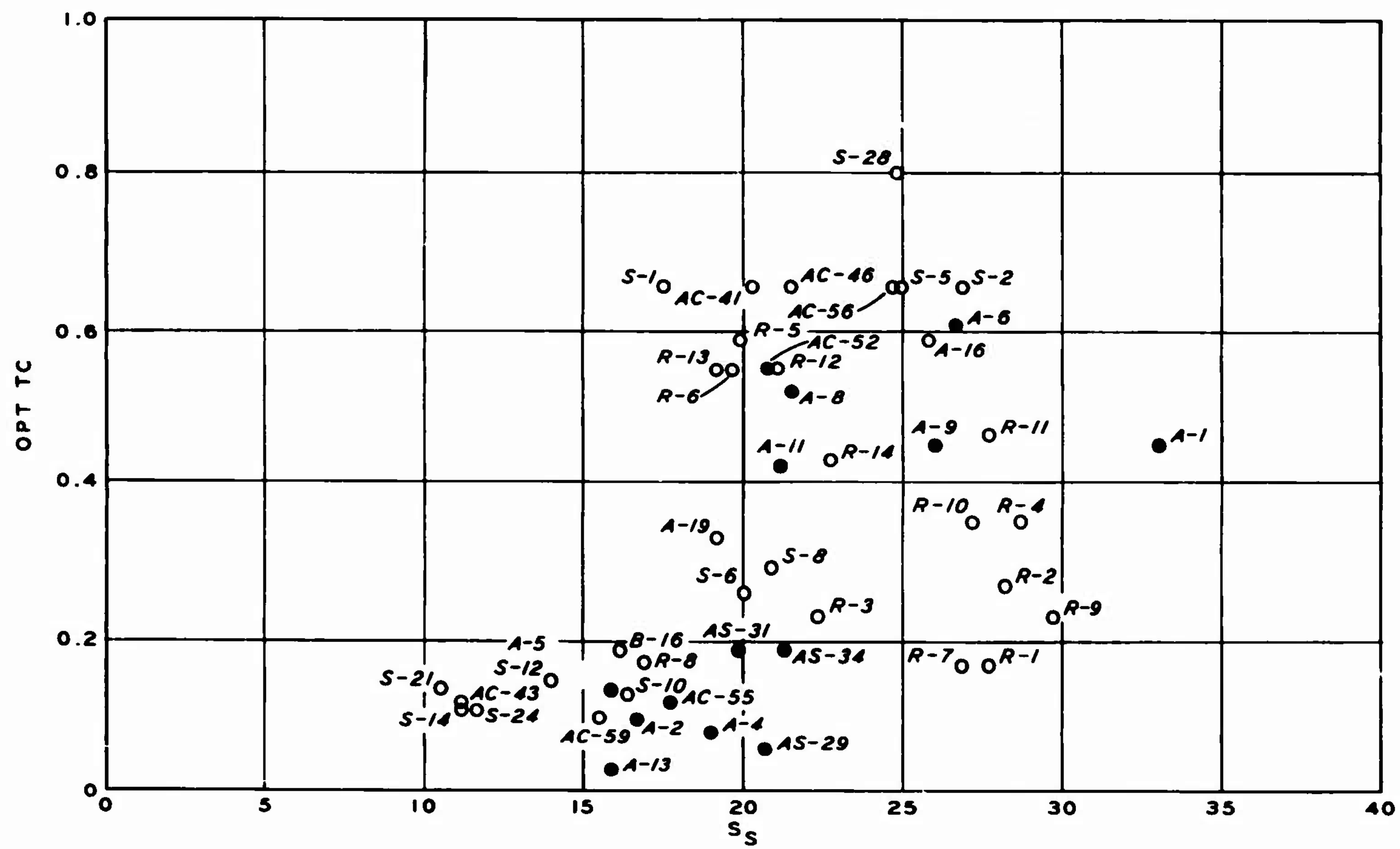

a. STRESS BUILDING (S) AND HANGAR 4 (B)
b. WES UPLAND AND BOTTOMLAND (A)
c. HICKS' FARM (AC)
d. SUNFLOWER CANAL ROAD (R)
e. MISSISSIPPI RIVER BEACH (AS)
OPT TC
S_S
LEGEND
○ TESTS ON PREPARED SURFACES
● TESTS ON NATURAL SURFACES
NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
OPT TC DATA ARE FROM TABLE 2.
S_S DATA ARE FROM TABLE 3.
OPT TC VS S_S
TREADED TIRES, 15% DEFLECTION
INDIVIDUAL TEST AREAS

PLATE 23



NOTE: NUMBERS NEAF PLOTTED POINTS ARE TEST NUMBERS.
LETTERS PRECEDING TEST NUMBERS IDENTIFY TEST AREAS.
OPEN SYMBOLS DENOTE PREPARED SURFACES; CLOSED SYMBOLS DENOTE NATURAL SURFACES.

OPT TC VS S_S

TREADED TIRES, 15% DEFLECTION

ALL DATA

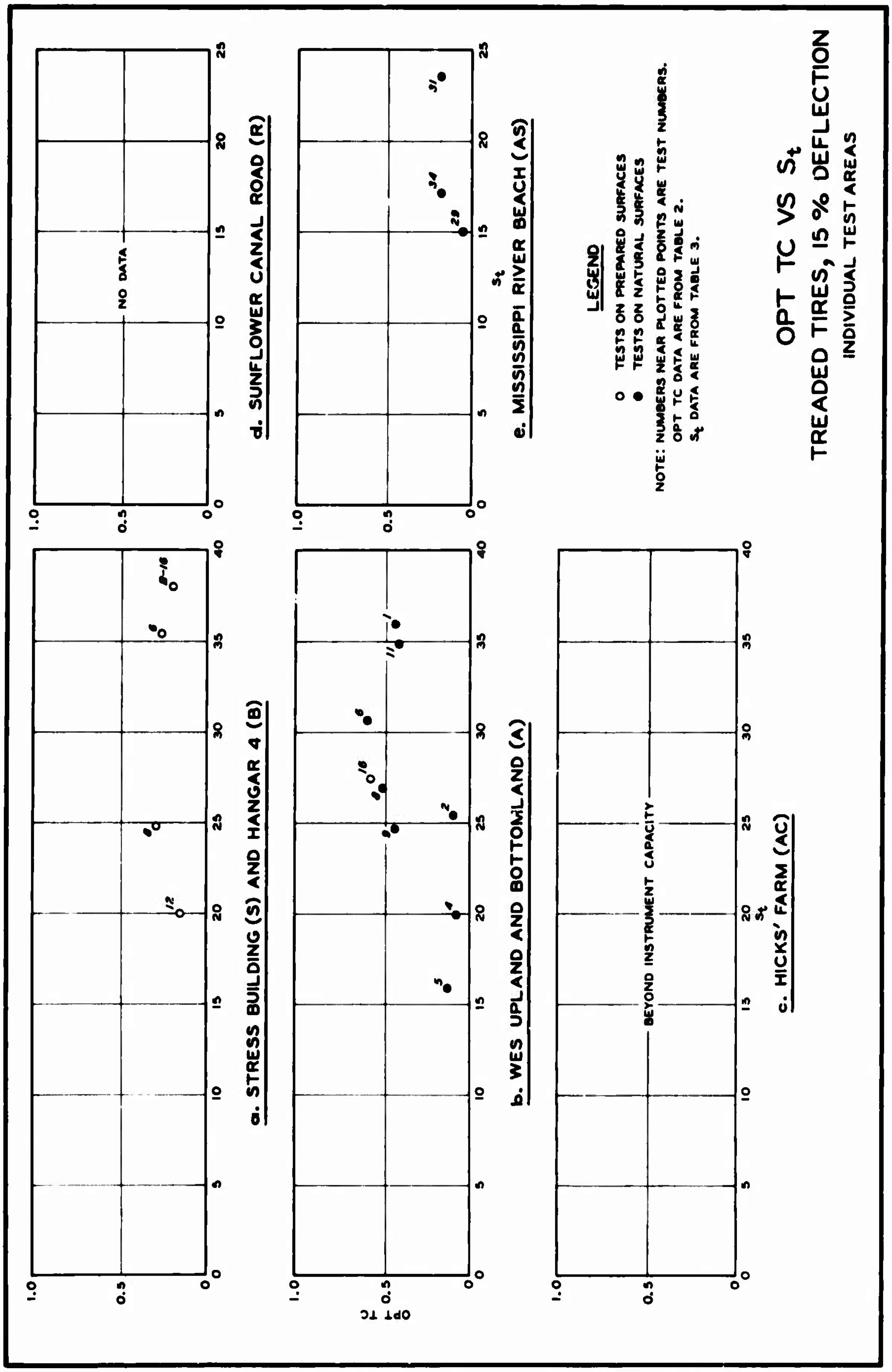
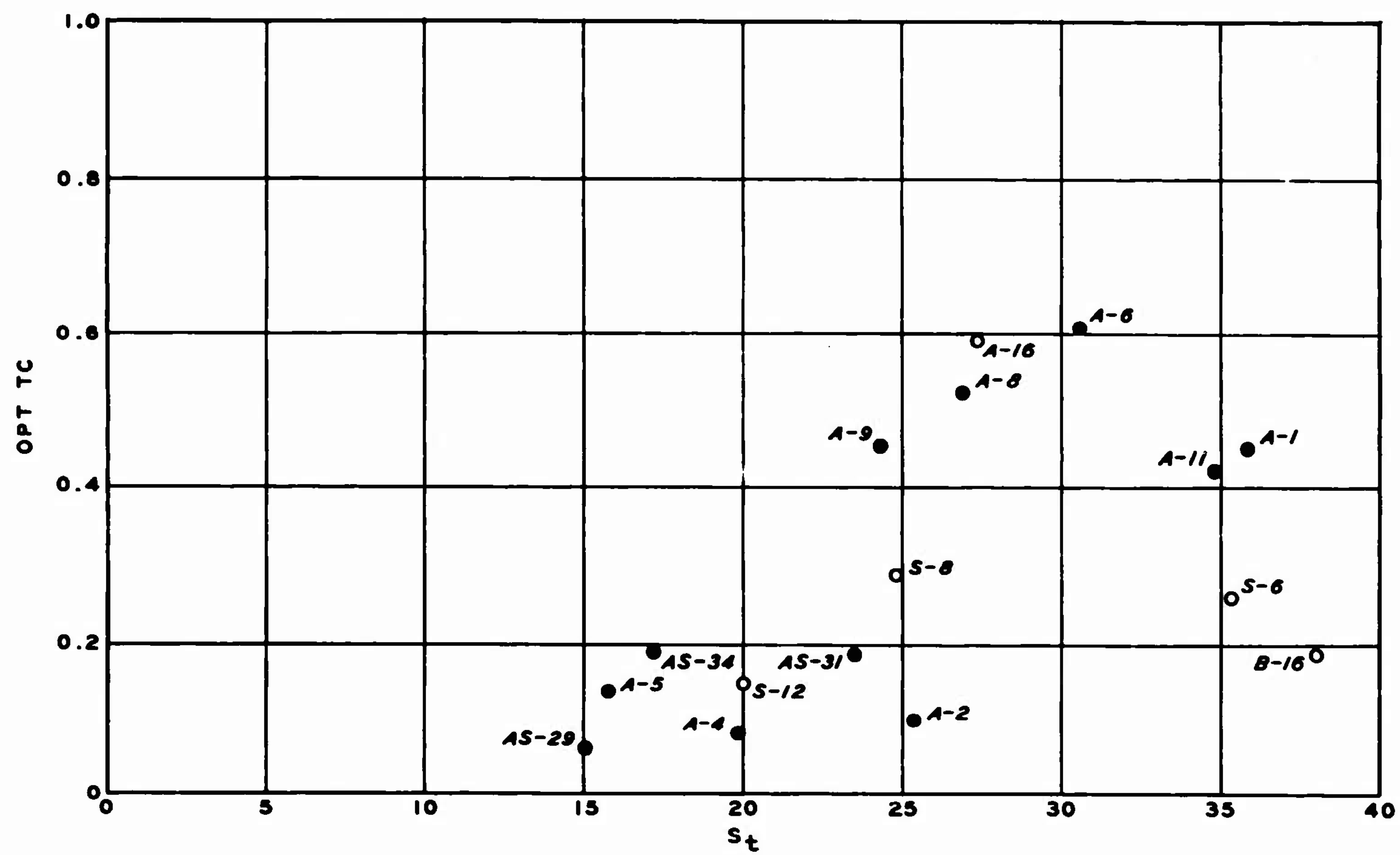

OPT TC VS S_t
TREADED TIRES, 15 % DEFLECTION
INDIVIDUAL TEST AREAS
a. STRESS BUILDING (S) AND HANGAR 4 (B)
b. WES UPLAND AND BOTTOMLAND (A)
c. HICKS' FARM (AC)
d. SUNFLOWER CANAL ROAD (R)
e. MISSISSIPPI RIVER BEACH (AS)
NO DATA
BEYOND INSTRUMENT CAPACITY
OPT TC
S_t
LEGEND
○ TESTS ON PREPARED SURFACES
● TESTS ON NATURAL SURFACES
NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
OPT TC DATA ARE FROM TABLE 2.
S_t DATA ARE FROM TABLE 3.

PLATE 25

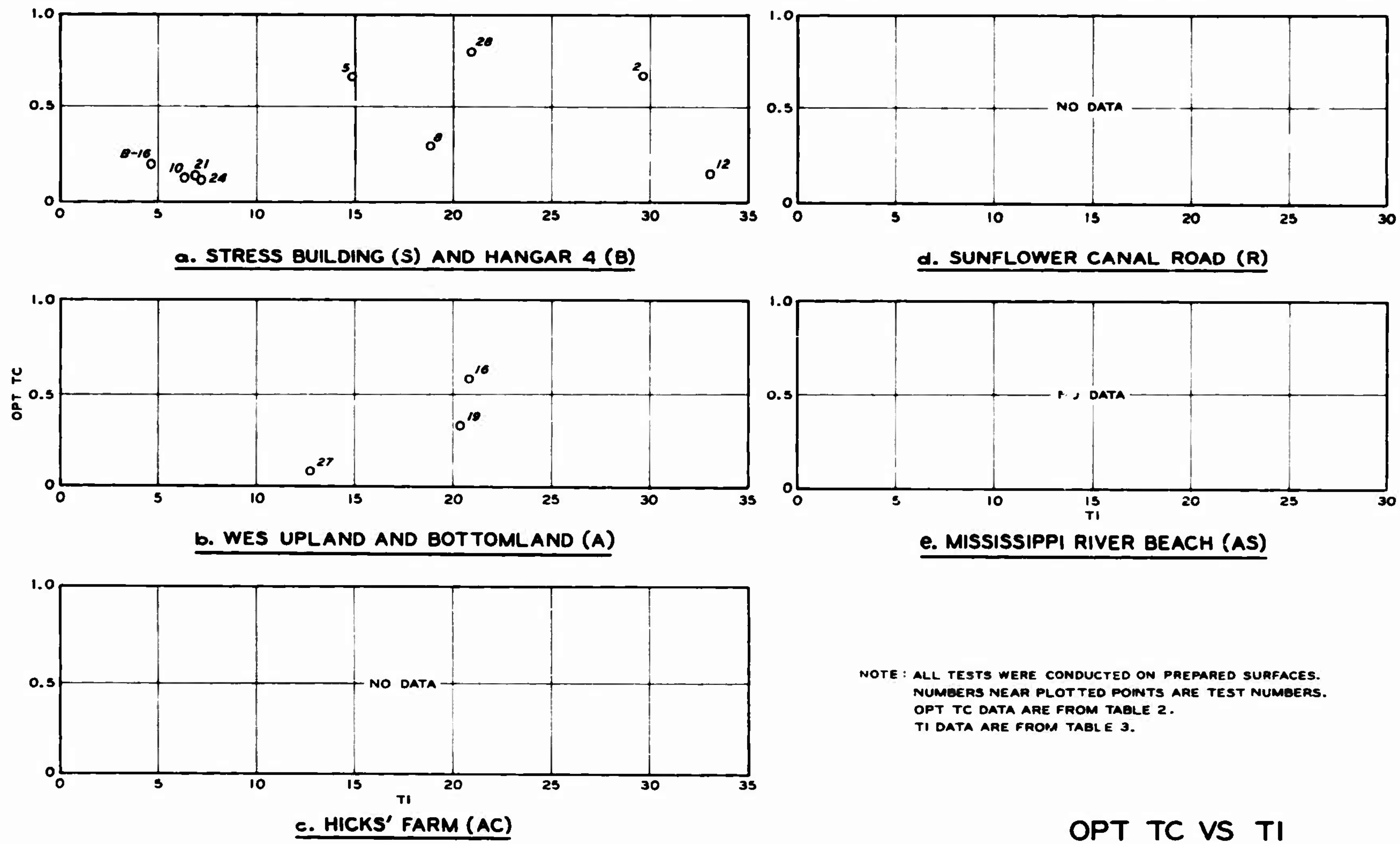


NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
LETTERS PRECEDING TEST NUMBERS IDENTIFY TEST AREAS.
OPEN SYMBOLS DENOTE PREPARED SURFACES; CLOSED SYMBOLS DENOTE NATURAL SURFACES.

OPT TC VS S_t

TREADED TIRES, 15% DEFLECTION

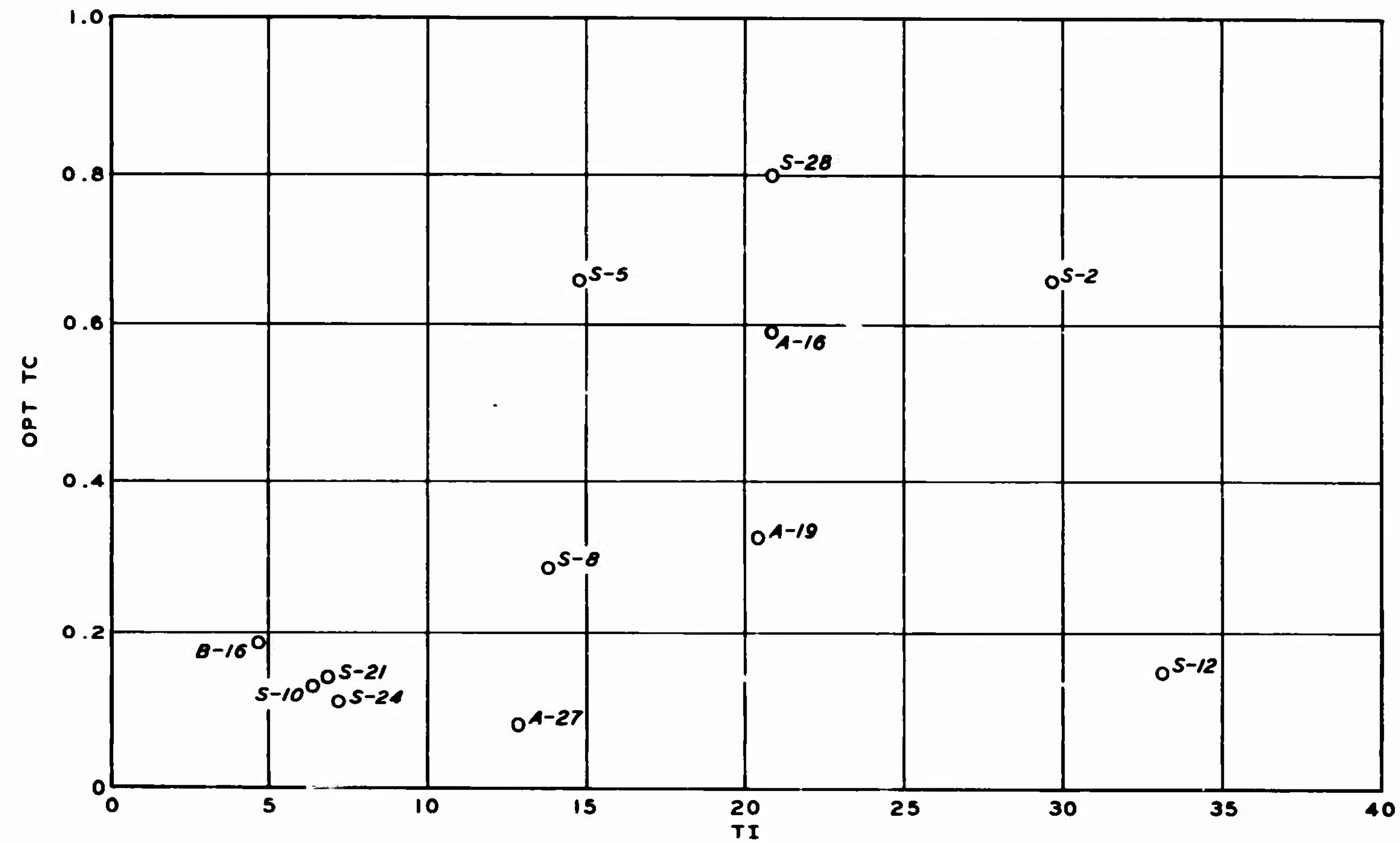
ALL DATA



NOTE: ALL TESTS WERE CONDUCTED ON PREPARED SURFACES.
NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
OPT TC DATA ARE FROM TABLE 2.
TI DATA ARE FROM TABLE 3.

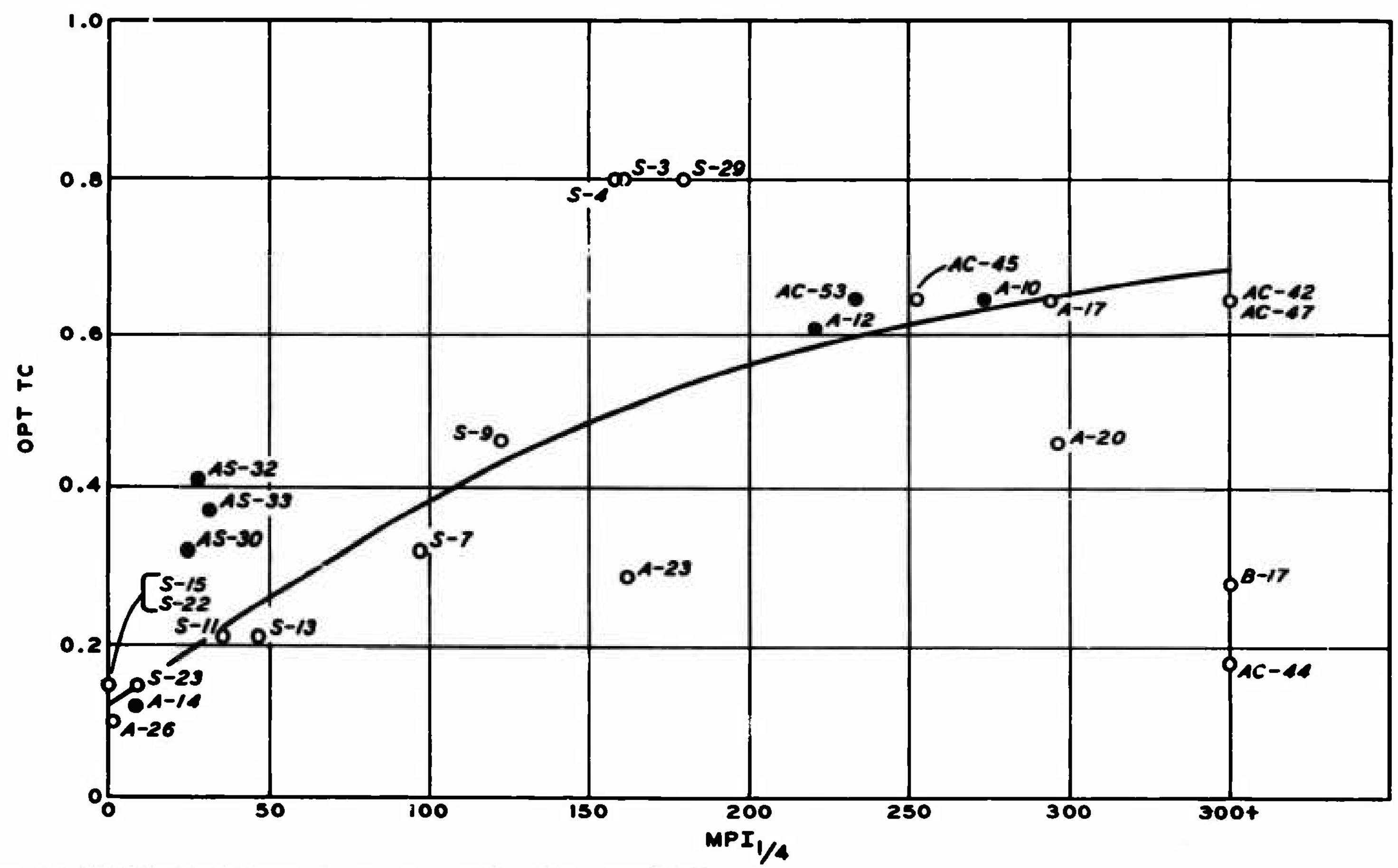
OPT TC VS TI
TREADED TIRES, 15 % DEFLECTION
INDIVIDUAL TEST AREAS

PLATE 27



NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
LETTERS PRECEDING TEST NUMBERS IDENTIFY TEST AREAS.
TESTS WERE CONDUCTED ON PREPARED SURFACES.
OPT TC DATA ARE FROM TABLE 2.
TI ARE DATA FROM TABLE 3.

OPT TC VS TI
TREADED TIRES, 15% DEFLECTION
ALL DATA



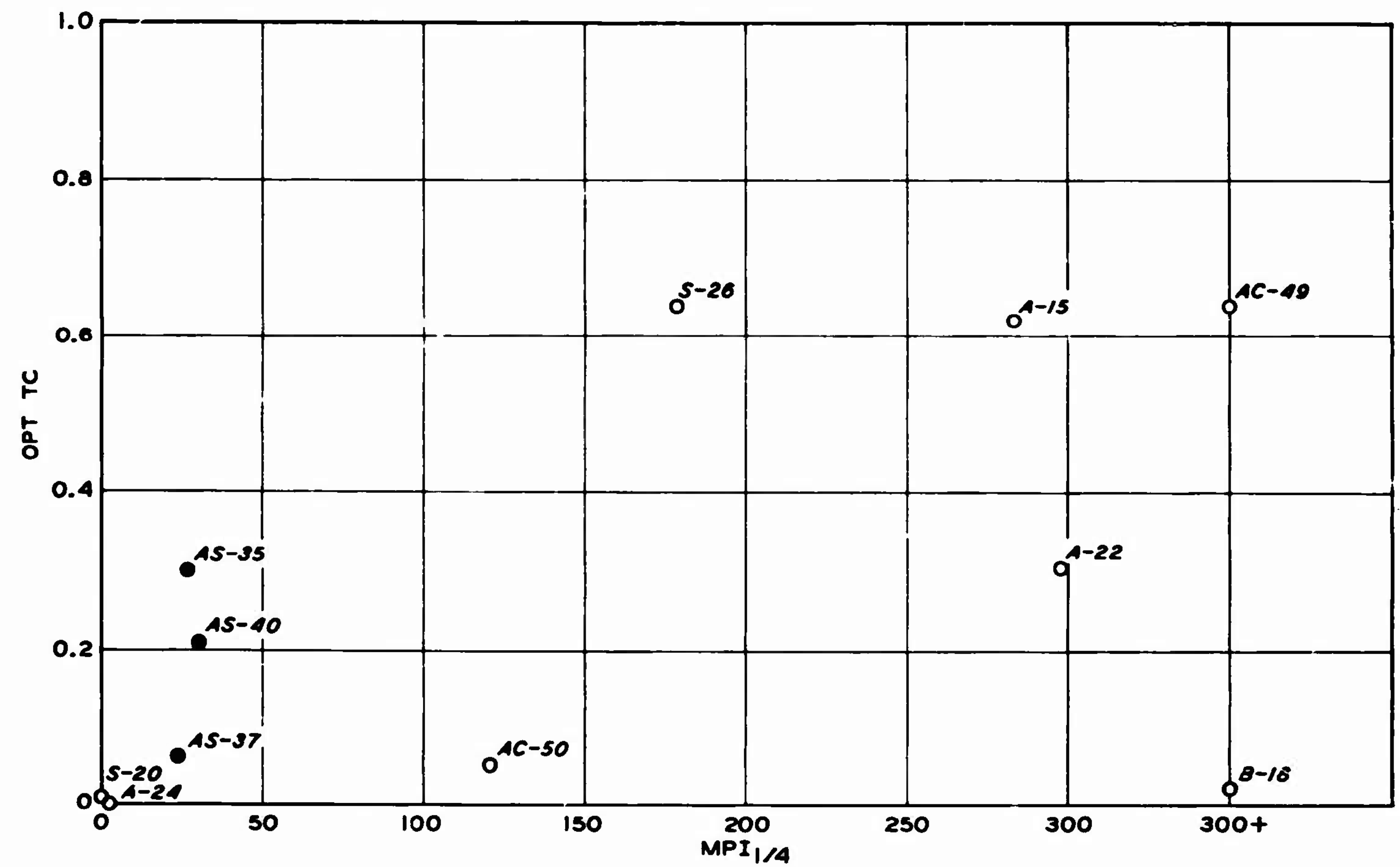
NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
LETTERS PRECEDING TEST NUMBERS IDENTIFY TEST AREAS.
OPEN SYMBOLS DENOTE PREPARED SURFACES; CLOSED SYMBOLS DENOTE NATURAL SURFACES.
OPT TC DATA ARE FROM TABLE 2.
$MPI_{1/4}$ DATA ARE FROM TABLE 3.

OPT TC VS $MPI_{1/4}$

TREADED TIRES, 35% DEFLECTION

ALL DATA

PLATE 29

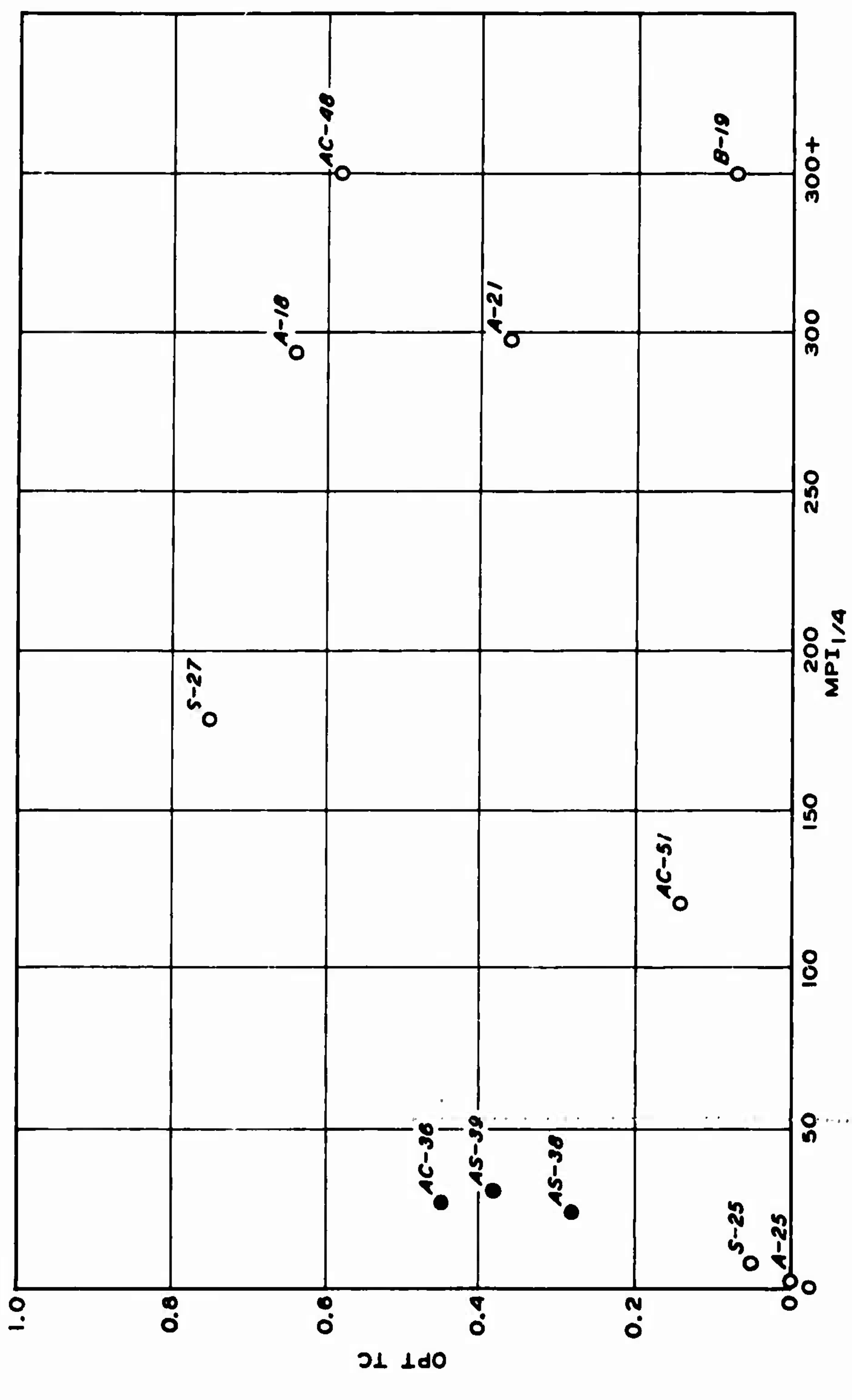


NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
LETTERS PRECEDING TEST NUMBERS IDENTIFY TEST AREAS.
OPEN SYMBOLS DENOTE PREPARED SURFACES; CLOSED SYMBOLS DENOTE NATURAL SURFACES.
OPT TC DATA ARE FROM TABLE 2.
$MPI_{1/4}$ DATA ARE FROM TABLE 3.

OPT TC VS $MPI_{1/4}$

SMOOTH TIRES, 15 % DEFLECTION

ALL DATA

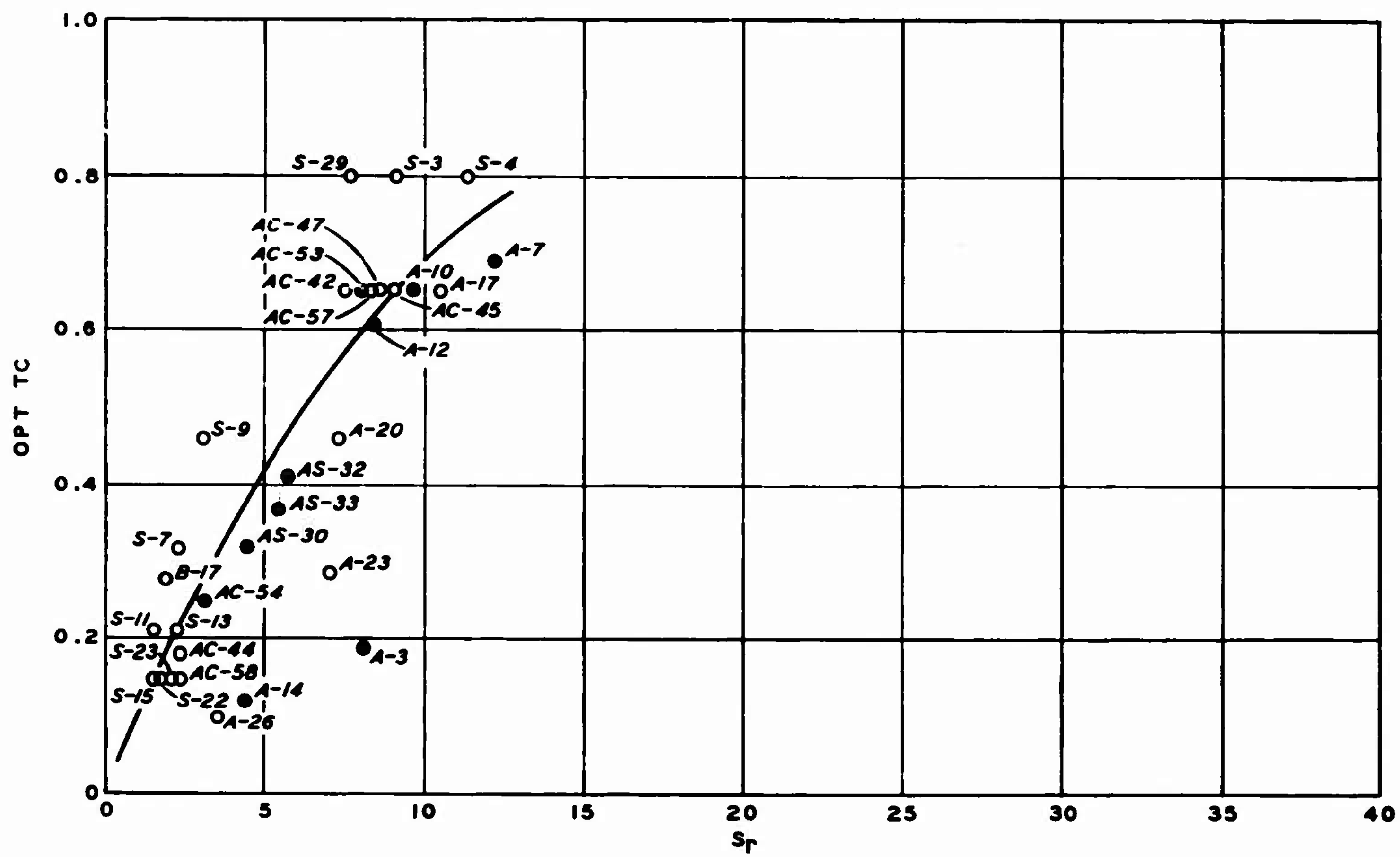


OPT TC VS $MPI_{1/4}$

SMOOTH TIRES, 35 % DEFLECTION

ALL DATA

NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
LETTERS PRECEDING TEST NUMBERS IDENTIFY TEST AREAS.
OPEN SYMBOLS DENOTE PREPARED SURFACES; CLOSED
SYMBOLS DENOTE NATURAL SURFACES.
OPT TC DATA ARE FROM TABLE 2.
$MPI_{1/4}$ DATA ARE FROM TABLE 3.

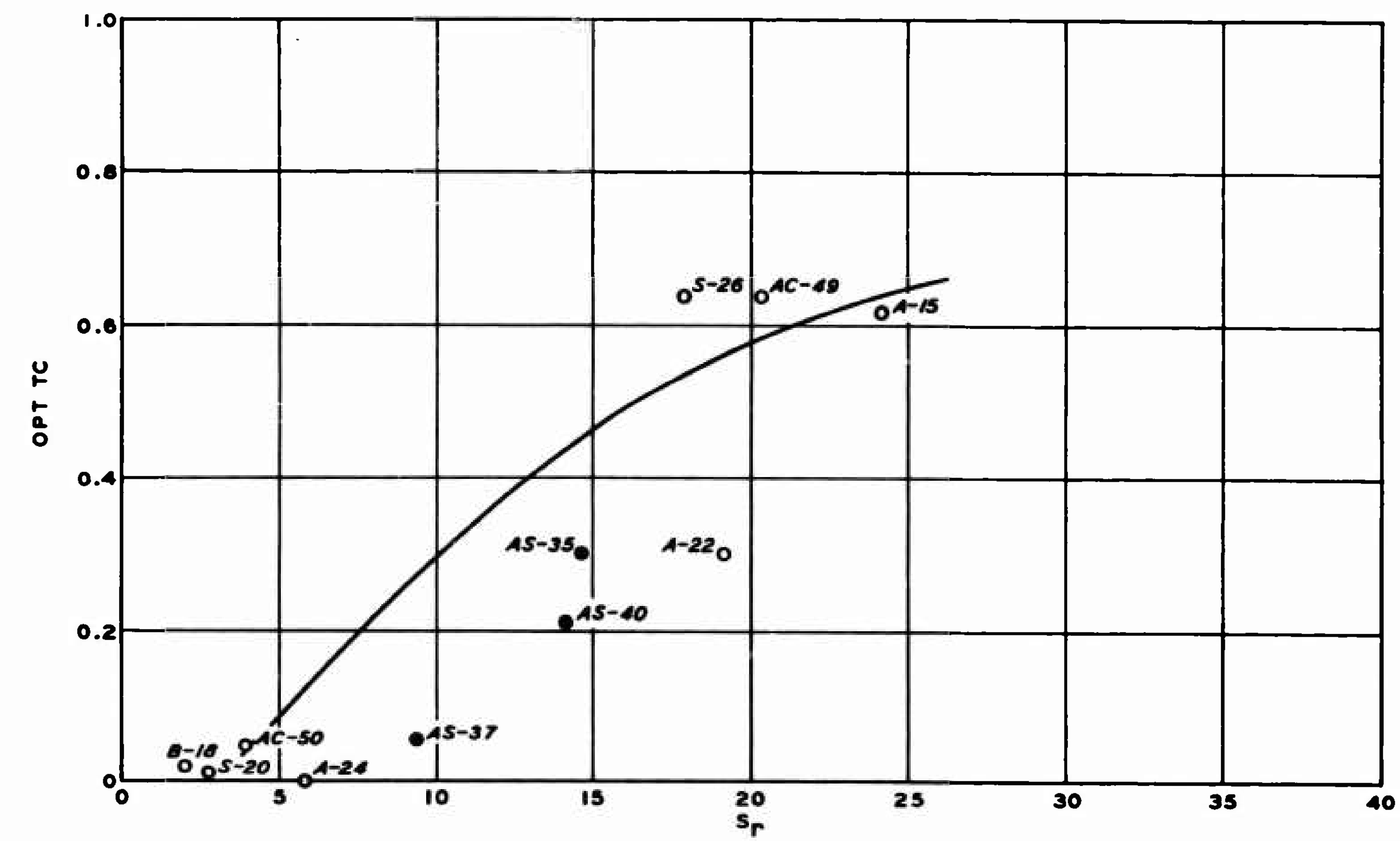


NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
LETTERS PRECEDING TEST NUMBERS IDENTIFY TEST AREAS.
OPEN SYMBOLS DENOTE PREPARED SURFACES; CLOSED SYMBOLS DENOTE NATURAL SURFACES.
OPT TC DATA ARE FROM TABLE 2.
S_r DATA ARE FROM TABLE 3.

OPT TC VS S_r

TREADED TIRES, 35% DEFLECTION

ALL DATA

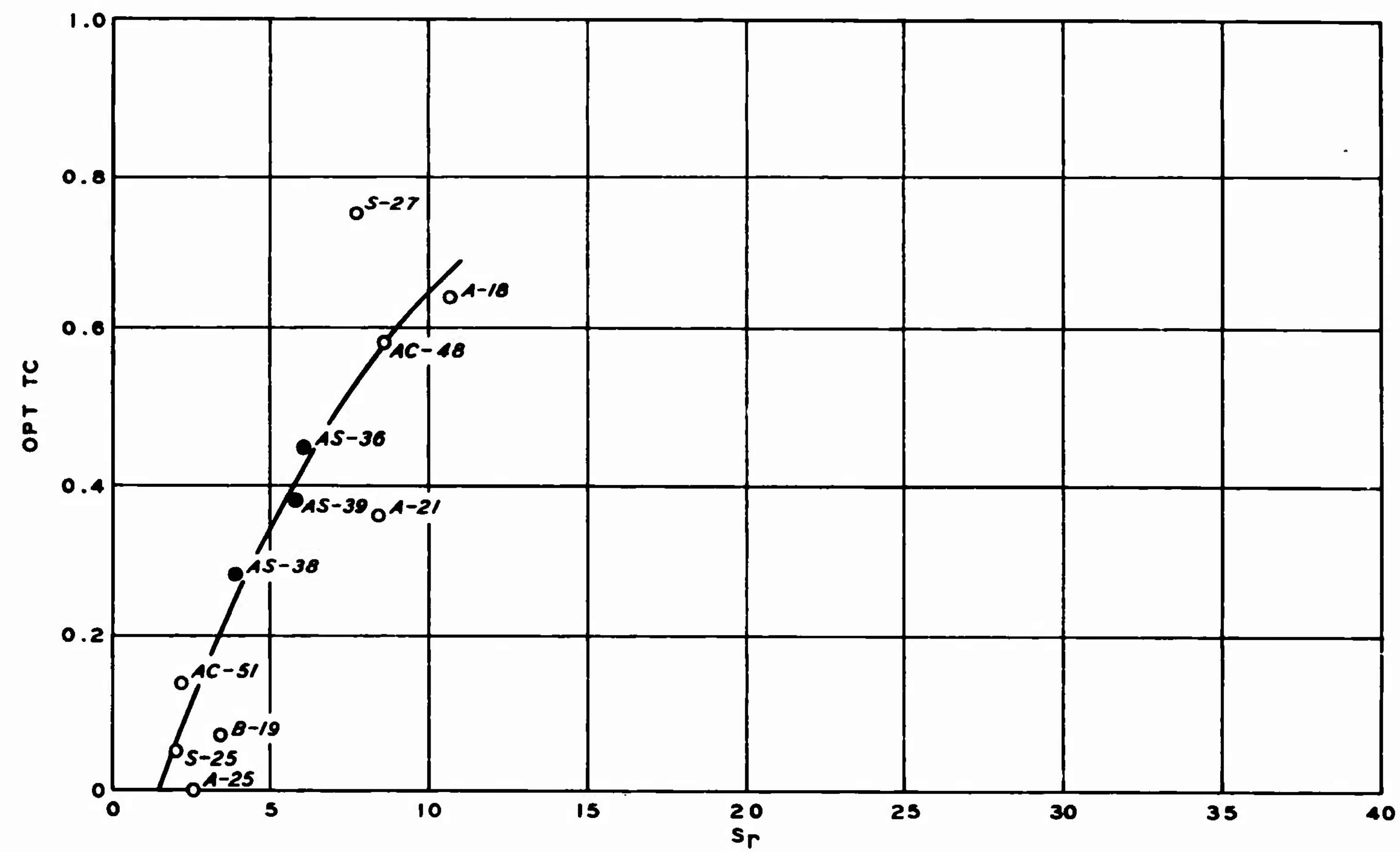


NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
LETTERS PRECEDING TEST NUMBERS IDENTIFY TEST AREAS.
OPEN SYMBOLS DENOTE PREPARED SURFACES; CLOSED SYMBOLS DENOTE NATURAL SURFACES.
OPT TC DATA ARE FROM TABLE 2.
S_r DATA ARE FROM TABLE 3.

OPT TC VS S_r

SMOOTH TIRES, 15% DEFLECTION

ALL DATA

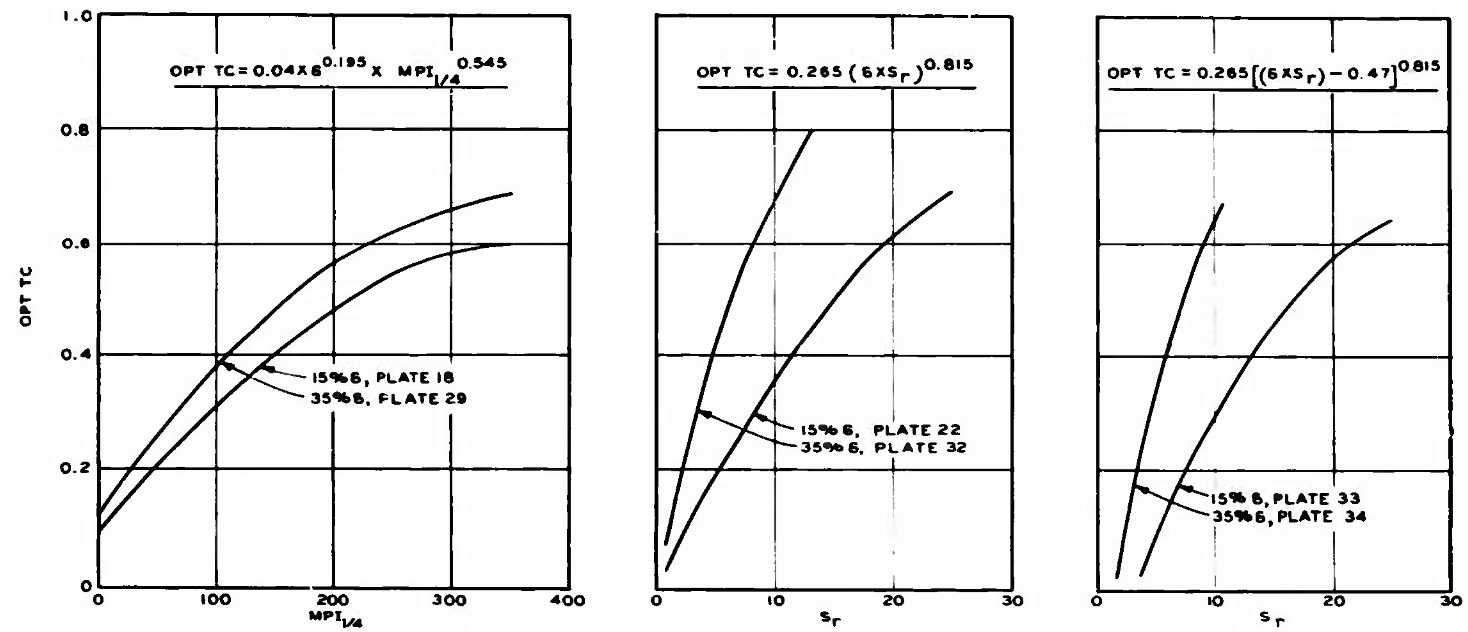


NOTE: NUMBERS NEAR PLOTTED POINTS ARE TEST NUMBERS.
LETTERS PRECEDING TEST NUMBERS IDENTIFY TEST AREAS.
OPEN SYMBOLS DENOTE PREPARED SURFACES; CLOSED SYMBOLS DENOTE NATURAL SURFACES.
OPT TC DATA ARE FROM TABLE 2.
S_r DATA ARE FROM TABLE 3.

OPT TC VS S_r

SMOOTH TIRES, 35% DEFLECTION

ALL DATA



a. TREADED TIRES; OPT TC VS $MPI_{1/4}$

b. TREADED TIRES; OPT TC VS S_r

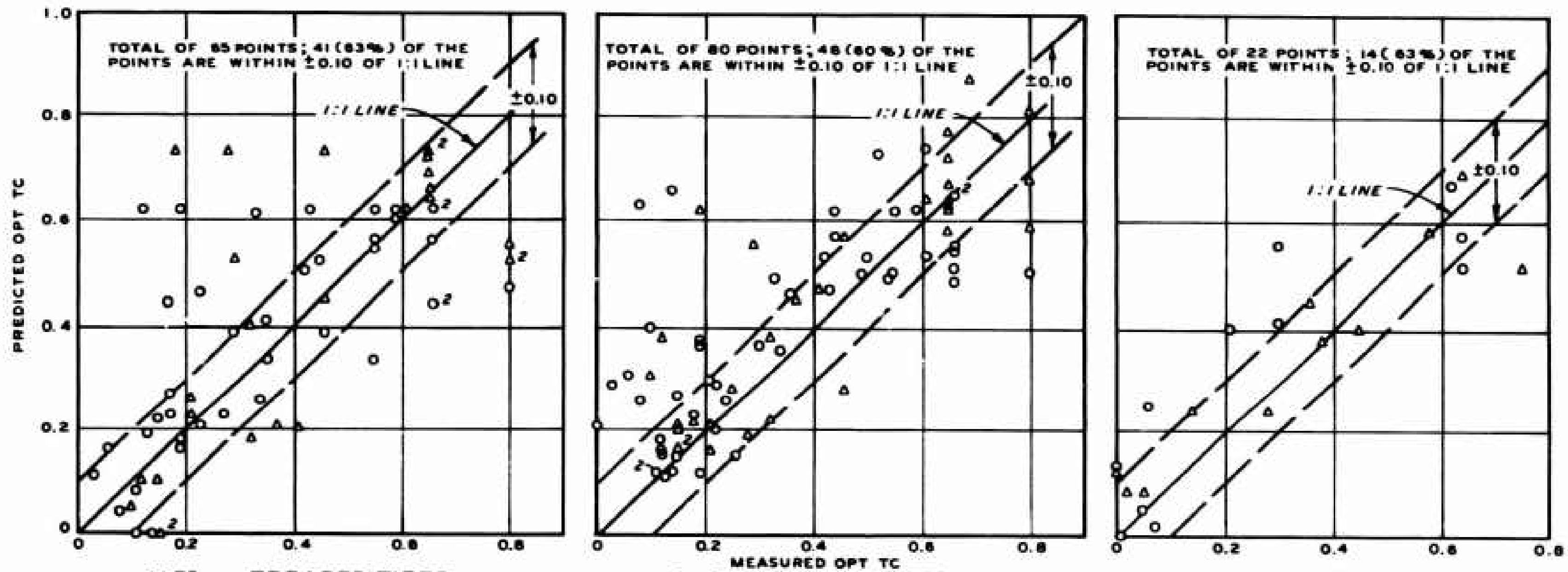
c. SMOOTH TIRES; OPT TC VS S_r

NOTE: δ DESIGNATES DEFLECTION

SUMMARY CURVES AND EQUATIONS FOR PREDICTING OPT TC

M37 3/4-TON TRUCK

9.00-16, 8PR TIRES (TREADED AND SMOOTH)



a. $MPI_{1/4}$; TREADED TIRES

b. S_r; TREADED TIRES

c. S_r; SMOOTH TIRES

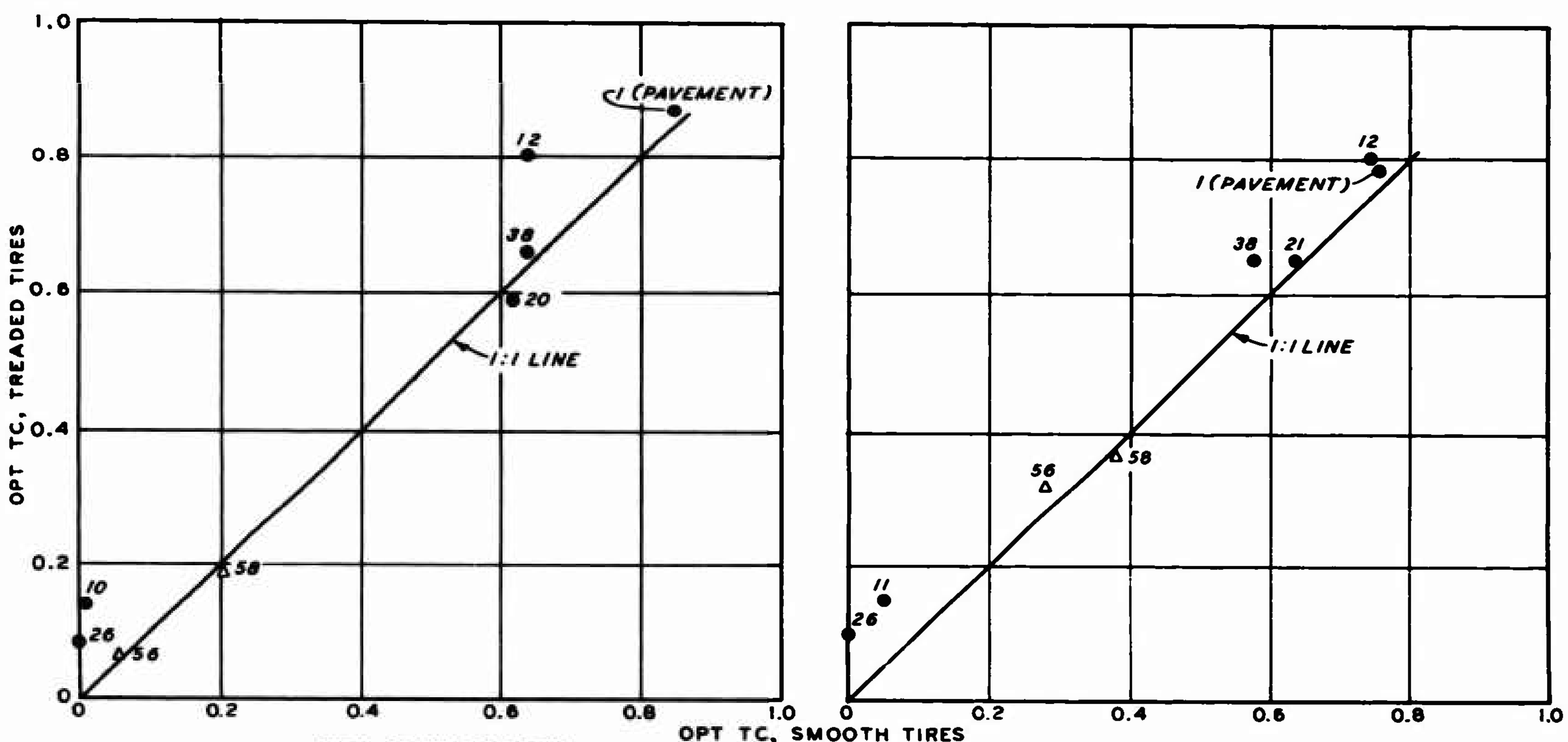
LEGEND

O 15% DEFLECTION
Δ 35% DEFLECTION

NOTE:

IN FIGURE	MEASURED OPT TC VALUES FROM	PREDICTED OPT TC VALUES FROM
a	PLATES 18 AND 29	EQUATION, FIG. a, PLATE 35
b	PLATES 22 AND 32	EQUATION, FIG. b, PLATE 35
c	PLATES 33 AND 34	EQUATION, FIG. c, PLATE 35

PREDICTED VS MEASURED OPT TC



a. 15% DEFLECTION

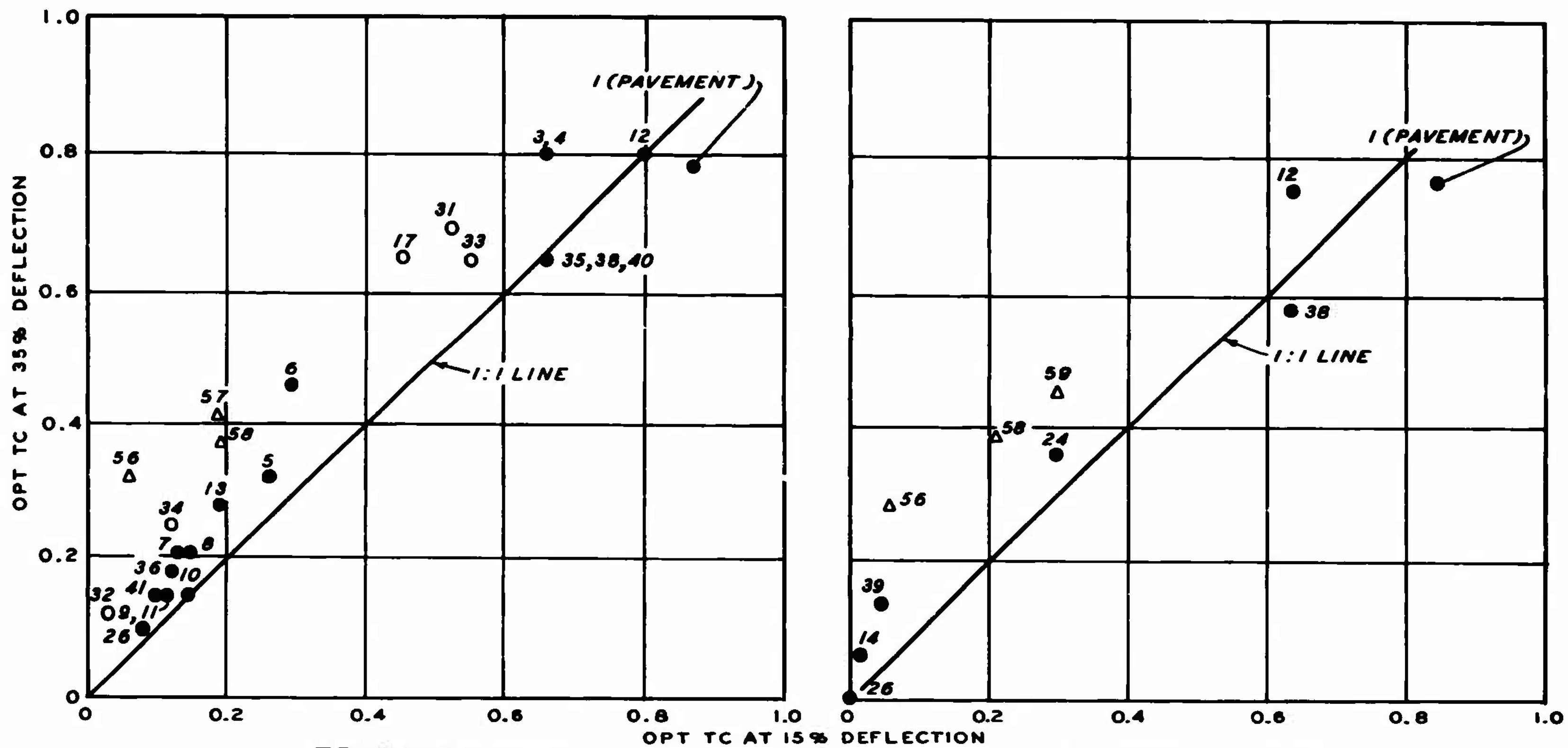
b. 35% DEFLECTION

LEGEND

● PREPARED SURFACE
Δ SAND

NOTE: NUMBERS NEAR PLOTTED POINTS ARE ITEM NUMBERS FROM TABLE 1.
DATA POINTS ARE FROM TABLE 2.

EFFECT OF TREAD PATTERN ON OPT TC



a. TREADED TIRES

b. SMOOTH TIRES

LEGEND

- O NATURAL SURFACE (EXCEPT SAND)
- ● PREPARED SURFACE
- Δ SAND

NOTE: NUMBERS NEAR PLOTTED POINTS ARE ITEM NUMBERS FROM TABLE 1.
DATA POINTS ARE FROM TABLE 2.

EFFECT OF DEFLECTION ON OPT TC